Transportation Management

Operational Networks

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ESD.260/15.770/1.260 Logistics Systems
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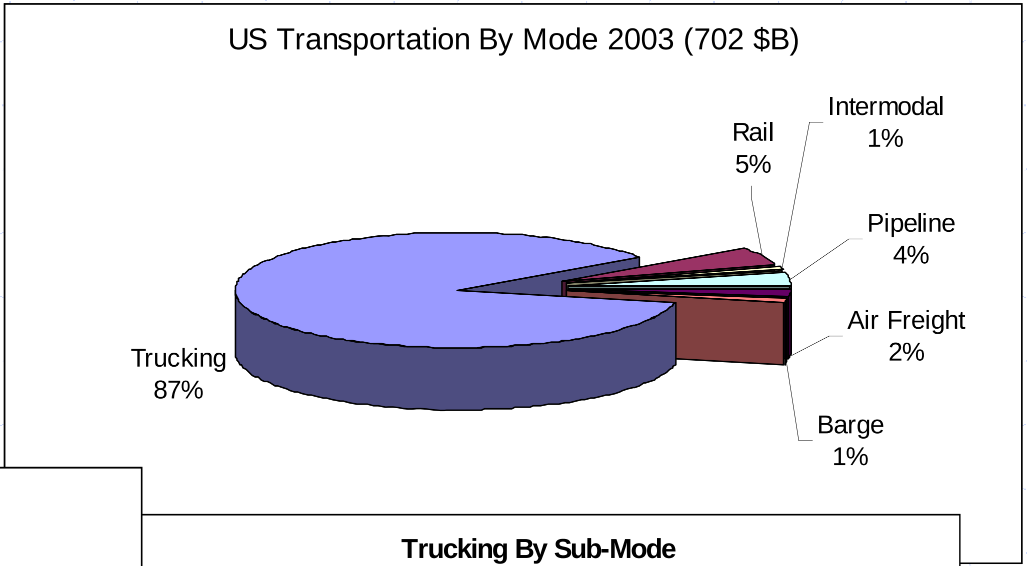
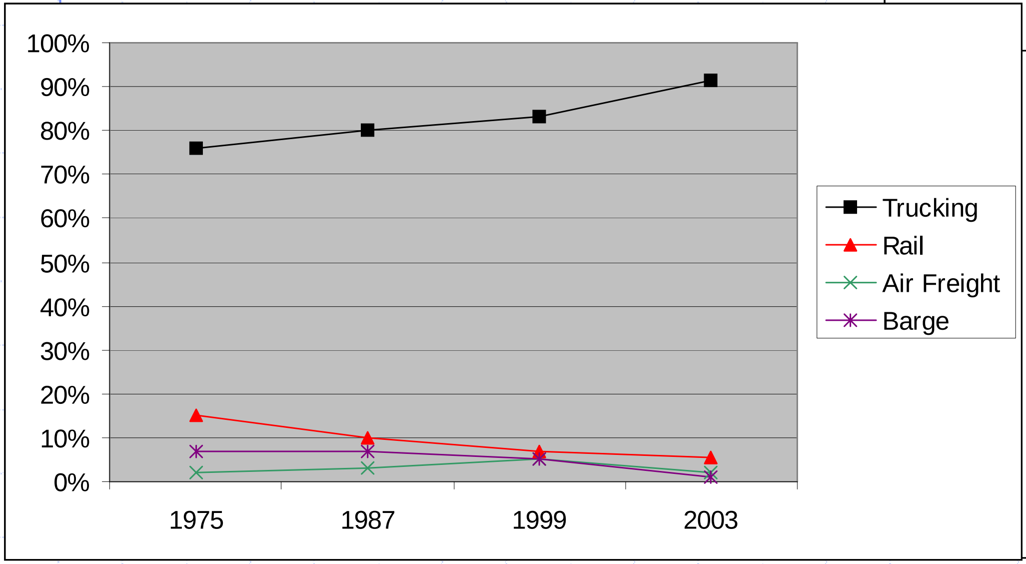
Agenda

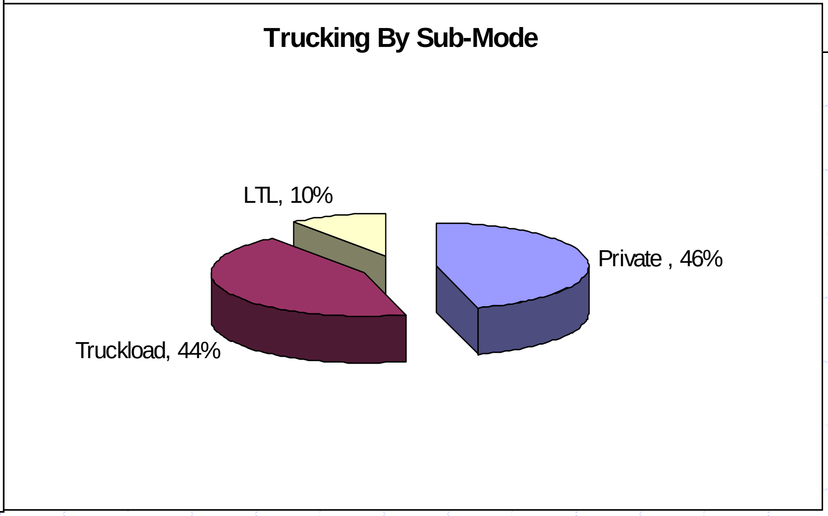
- Economic vs Traditional Modes
- Operational Networks
  - One to One
  - One to Many
  - Many to Many
- Example of Approximate Analysis

Traditional Transport Modes (US)

Mode	2003 revenue ($B)	
Trucking	610	87%
Rail	36	5%
Intermodal	8	1%
Pipeline	27	4%
Air Freight	13	2%
Barge	8	1%
	702	100%





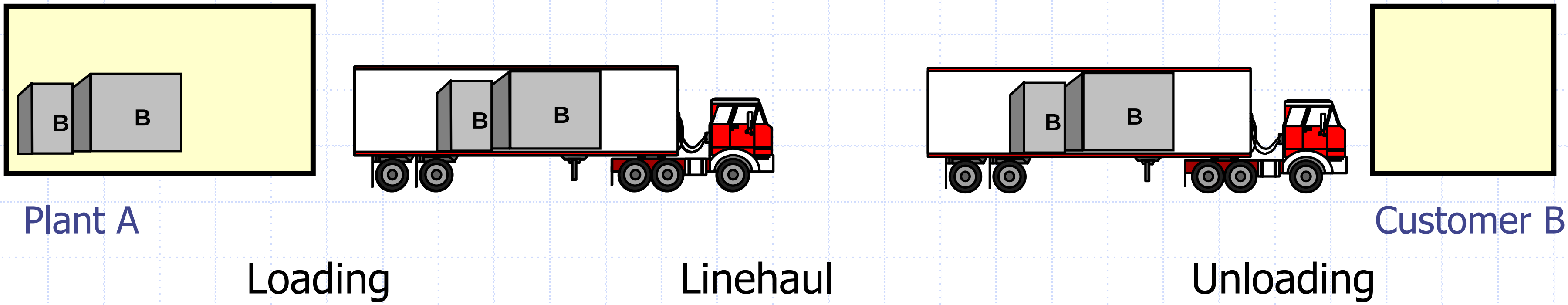


Note that these modes are all technology based – according to the type of power unit and guideways used.

The Transportation Product

- Four Primary Transportation Components
  - Loading/Unloading
  - Line-Haul
  - Local-Routing (Vehicle Routing)
  - Sorting
- Basic Forms of Consolidation
  - Vehicle
  - Temporal
  - Spatial
- Driving Influences
  - Economies of Scale
  - Economies of Scope (Balance)
  - Economies of Density

The Transportation Product



- Loading/Unloading
  - Key drivers:
    - Number of items
    - Time
    - Stowability (Packaging)
  - Not always symmetric
- Linehaul
  - Key drivers:
    - Distance
    - Balance / Backhaul
  - Impacted by network
    - Congestion
    - Connectivity

Regression of Long Haul TL Rates

		95% Confidence Limits	
Independent Variable	**Coefficient Value**	**Lower Bound**	**Upper Bound**
(Constant)	116.84	107.57	126.12
Distance	1.10	1.097	1.101
OutBound Flag	9.04	5.48	12.61
Private Fleet Dist	(0.17)	(0.21)	(0.13)
Spot Mkt Dist	0.29	0.26	0.32
Intermodal Dist	(0.29)	(0.30)	(0.29)
Expedited Dist	0.15	0.13	0.16
High Frequency Flag	(72.49)	(78.44)	(66.54)
Monthly Flag	(60.96)	(64.44)	(57.49)
Quarterly Flag	(36.33)	(38.96)	(33.69)
$100M Buy Flag	(19.2840)	(23.85)	(14.71)
Regional Values	XXX	XX	

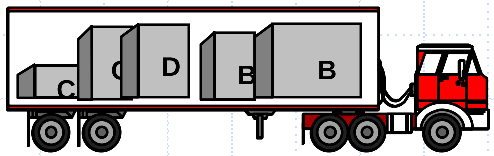
Explains ~77% [(Constant), Distance]

Explains ~ 2% [OutBound Flag through $100M Buy Flag]

Explains ~ 7% [Regional Values]

The Transportation Product

Plant A



Customer B

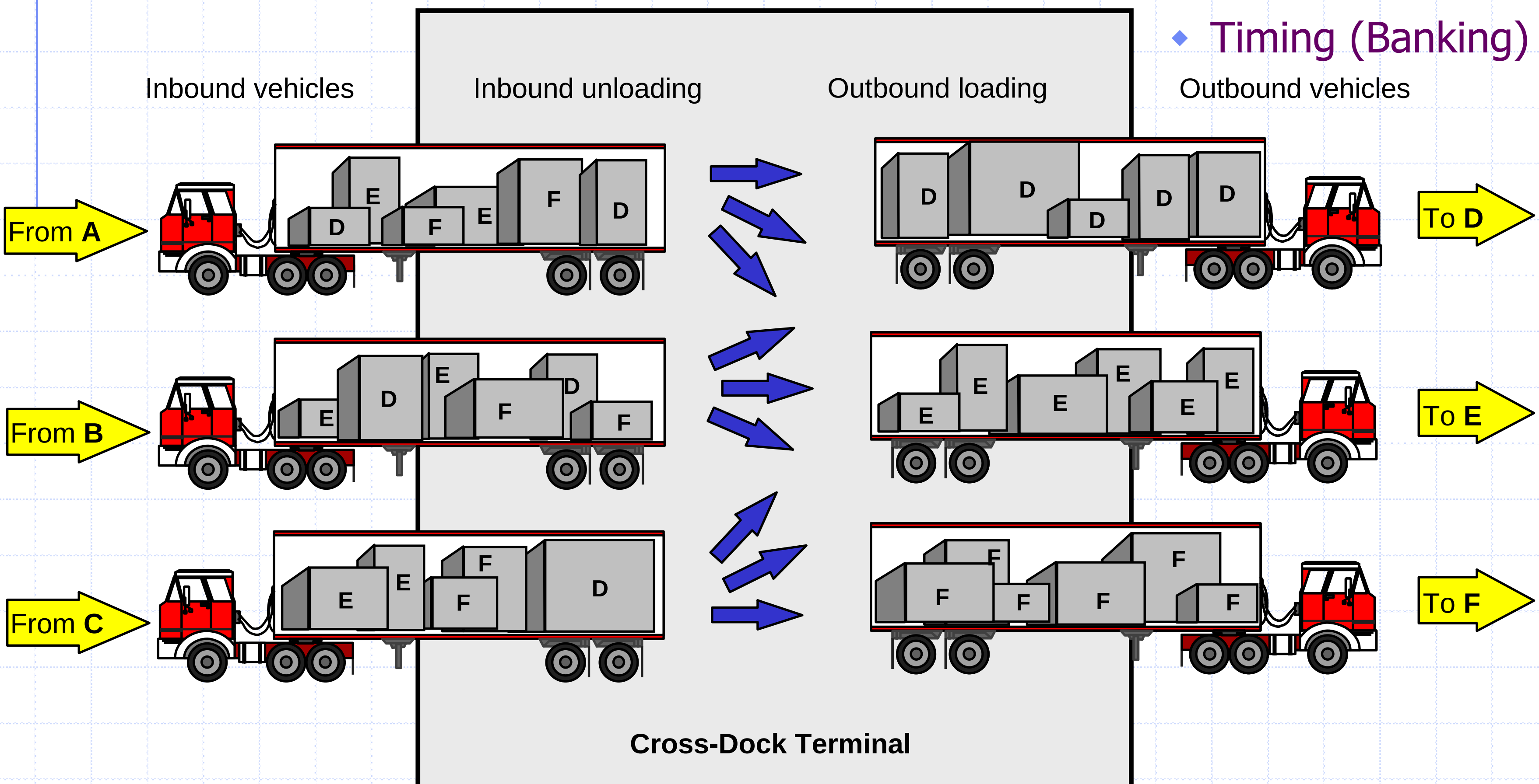
- Vehicle Routing
  - Key drivers:
    - Number/Density of stops
    - Vehicle Capacity
    - Time
  - Origin or Destination
    - One to Many
    - Many to One
    - Interleavened

Customer D

Customer C

The Transportation Product

- Sorting
  - Key drivers:
    - Stowability (Packaging)
    - Number of items
    - Timing (Banking)



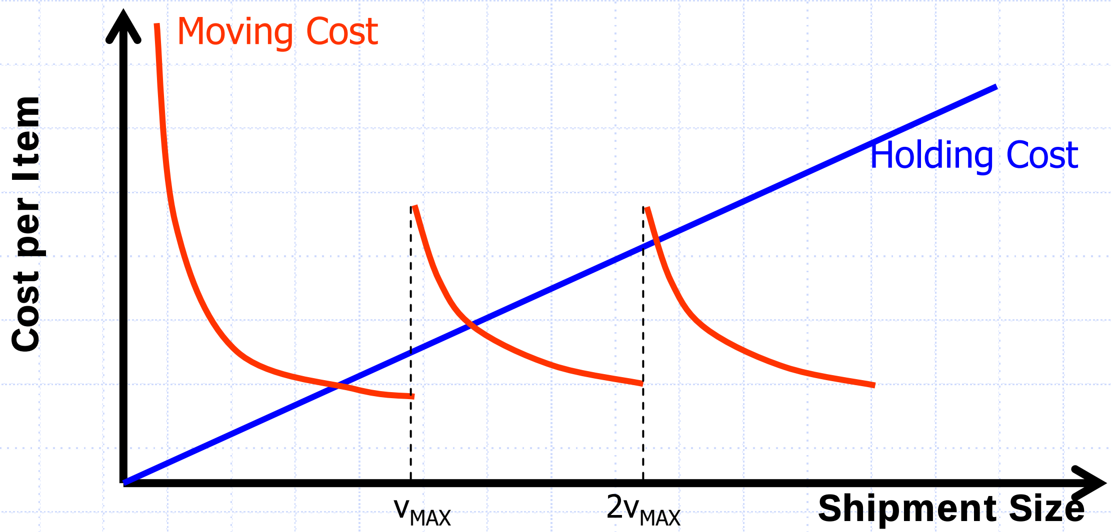
Material Adapted from Yossi Sheffi

The Transportation Product

- Four Primary Transportation Components
  - Loading/Unloading
  - Line-Haul
  - Local-Routing (Vehicle Routing)
  - Sorting
- Basic Forms of Consolidation
  - Vehicle
  - Temporal
  - Spatial
- Driving Influences
  - Economies of Scale
  - Economies of Scope (Balance)
  - Economies of Density

Economies of Scale

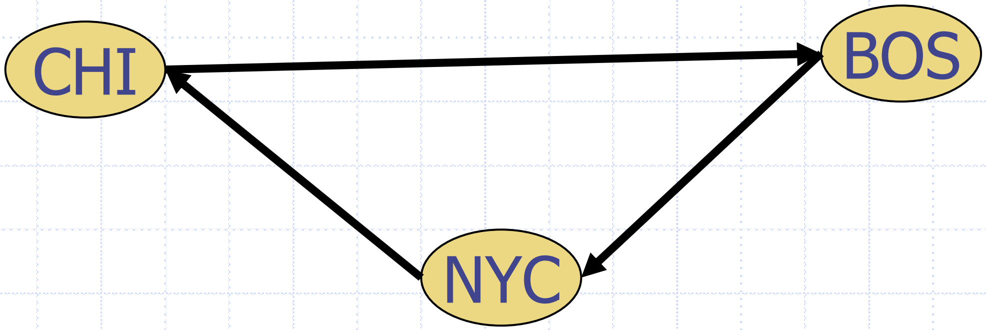
- For an individual shipment –
  - Captures allocation of fixed costs over many items
  - Follows lot sizing logic – drives mode selection



- Across a network – this is less clear
  - Volume on all lanes increase in the same proportion
  - It depends on directionality (mainly direct carriers)
  - Consolidated carriers have more fixed costs - more terminals

Economies of Scope (Balance)

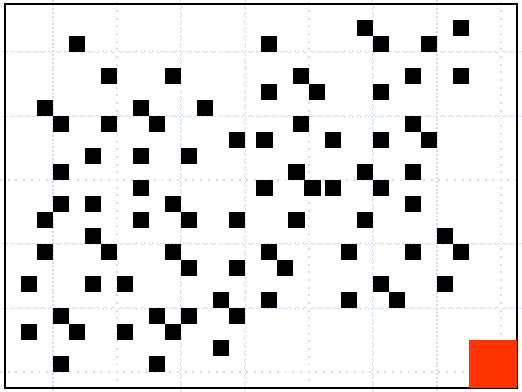
- Reverse flow mitigates the cost of repositioning.
- Strong for direct carriers – but present in all
  - Subadditivity - the costs of serving a set of lanes by a single carrier is lower than the costs of serving it by a group of carriers
  - Cost Complementarity - the effect that an additional unit carried on one lane has on other lanes

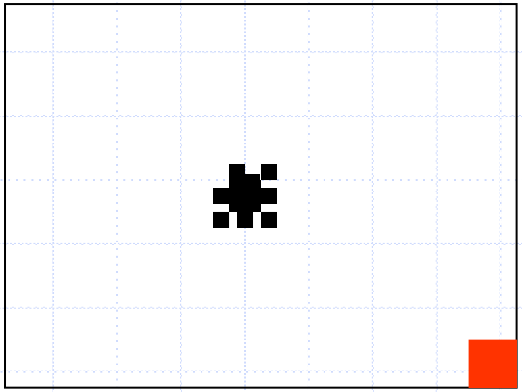


Economies of Density

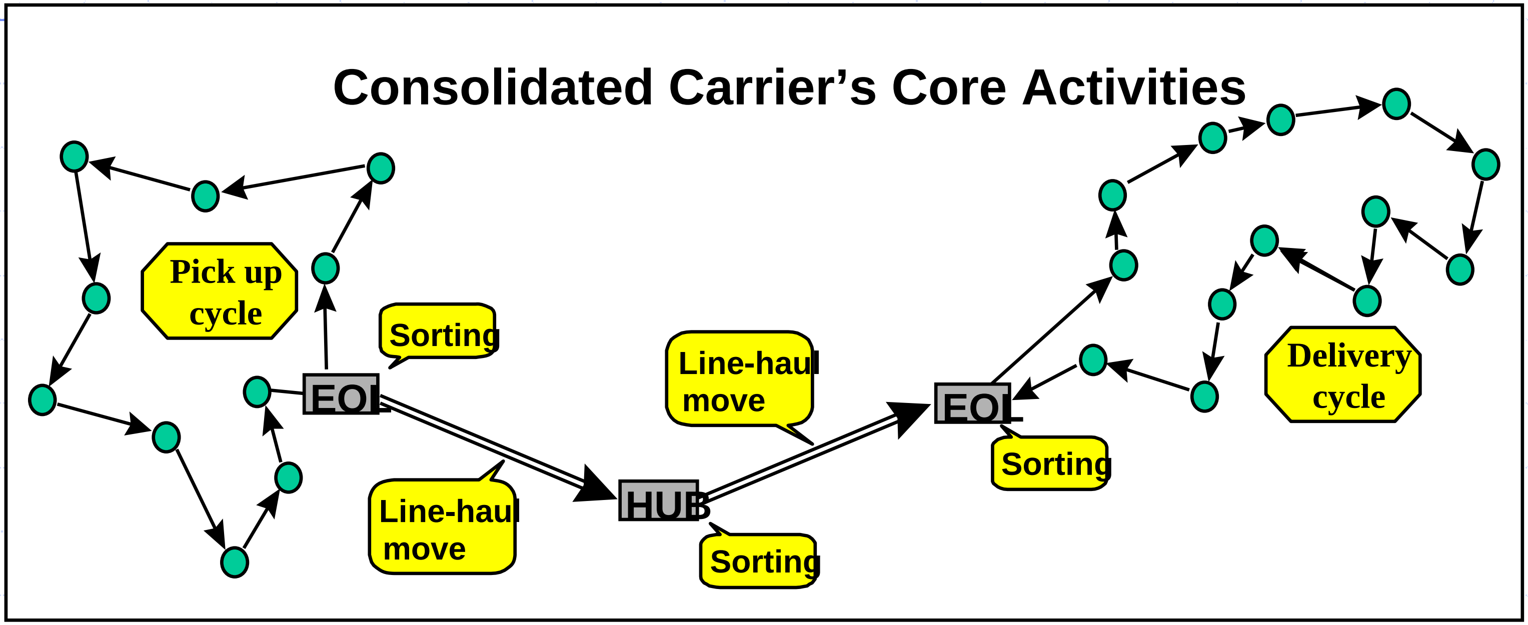
- Strong for Consolidated Carriers
  - Location Density
    - Number of customers per unit area
  - Shipment Density
    - Average number of shipments at a customer location
    - Daily average volume is critical

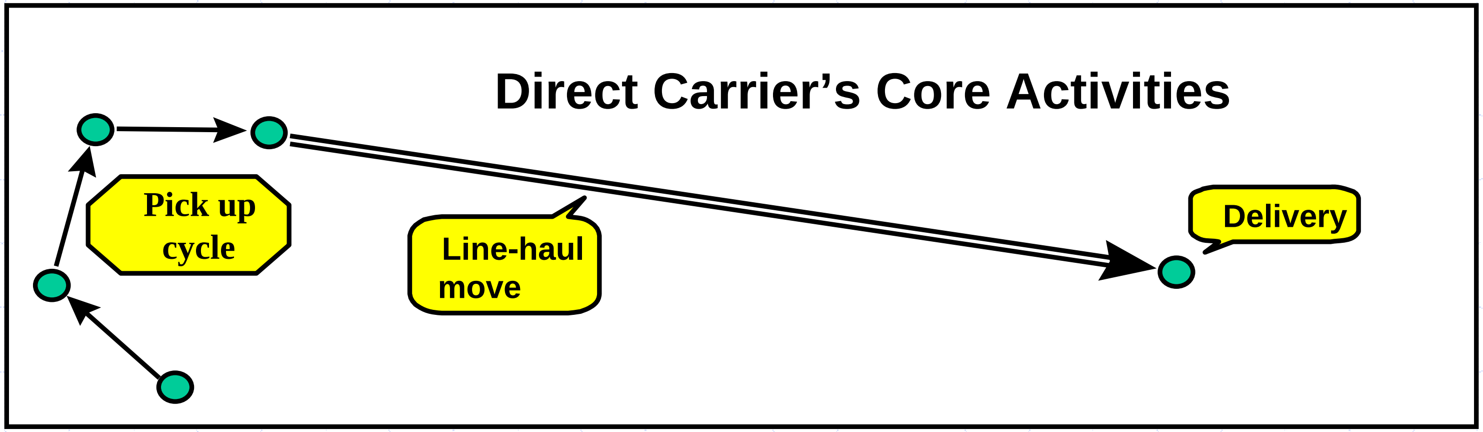
Which is better?





Economic Modes





Economic Modes

Consolidated operations (CO)

- Bus/rail transit
- LTL
- Rail
- Airlines
- Ocean carriers/liner service
- Package delivery

Direct operations (DO)

- Taxi
- TL
- Unit trains
- Charter/private planes
- Tramp services
- Courier

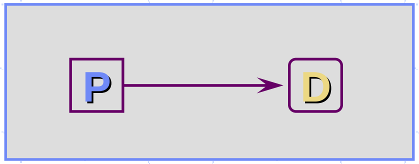
DO conveyances on CO carriers (sub-consolidation)

- Rail cars
- Ocean containers
- Air "igloos"

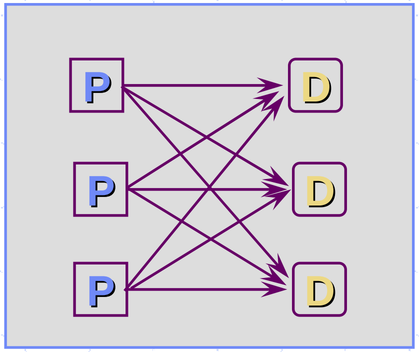
Operational Network (ONW) Structure

- One to One
  - Direct Network
- One to Many / Many to One
  - Direct with Milk Runs
  - Consolidation within the Vehicle

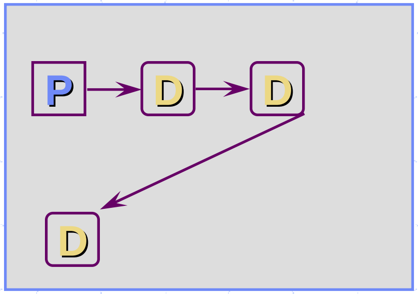
One to One



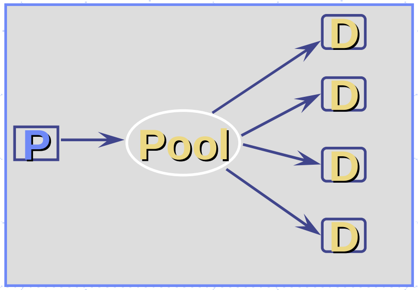
One to One



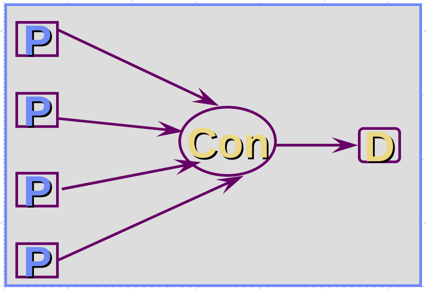
One to Many



Pool / Zone Skipping



M21 w/Tranship

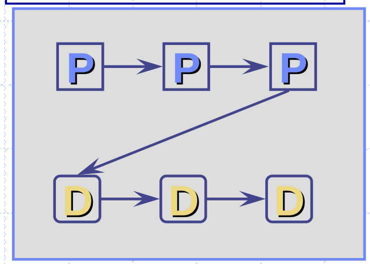


P - Pickup Location **D - Delivery Location**

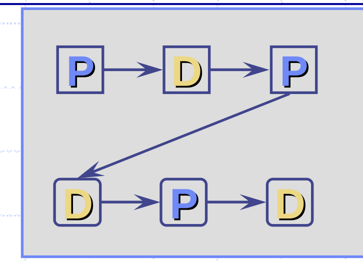
Operational Network (ONW) Structure

- Many to Many
  - No Transhipment Point
    - Direct with Milk Runs
  - With Transhipment Point
    - Direct with DC (Cross Docking)
    - Direct with Milk Runs

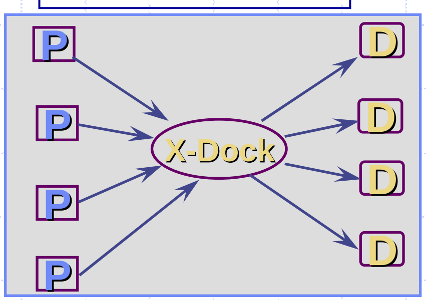
Many to Many



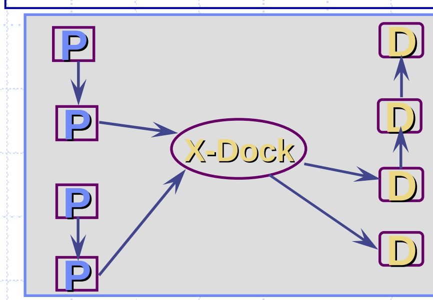
M2M Interleaved



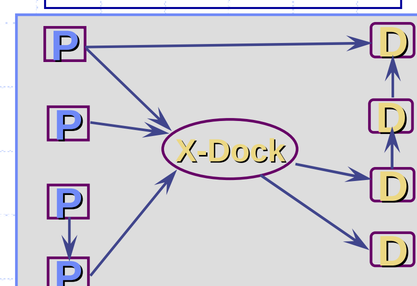
Direct w/ DC



Direct w/ Milk Runs



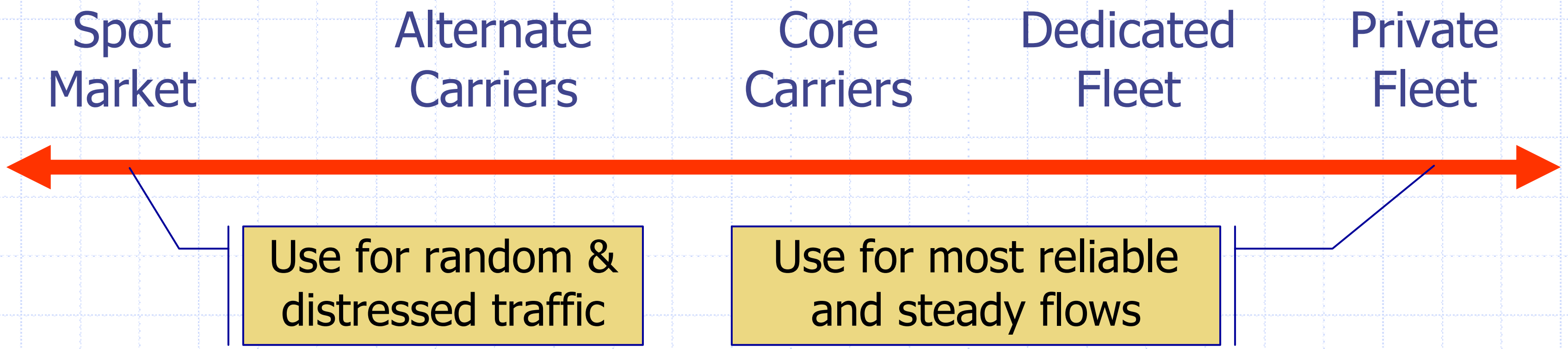
Hub w/ Directs



P - Pickup Location **D - Delivery Location**

Decisions – Contract Type

- What type of relationship do you need to establish with your carriers?
- Continuum of relationships from one-off to ownership
  - Ownership of Assets versus Control of Assets
  - Responsibility for utilization
  - On-going commitment / responsibilities
  - Shared Risk/Reward – Flexible contracts



Solution Approaches for ONW

- Math Programming / Algorithmic Approach
  - Develop detailed objective function and constraints
  - Requires substantial data
  - Solve MILP to optimality
- Simulation Approach
  - Develop detailed rules and relationships
  - Simulate the expected demand patterns
  - Observe results and rank different scenarios
- Approximation Approach
  - Develop a Total Cost Function that incorporates the relevant decision variables
  - Obtain reasonable results with as little information as possible in order to gain insights
  - Detailed data can actually make the optimization process harder

Total Cost Per Item Function

Cost per item = Holding Costs + Moving Costs

= (Inventory Cost) + (Transport Cost + Handling Cost)

$$TC(Q) = vD + A\left(\frac{D}{Q}\right) + rv\left(\frac{Q}{2}\right)$$

$$CostPerItem = \frac{TC(Q)}{D} = v + \frac{A}{Q} + rv\left(\frac{T}{2}\right)$$

$$ShipmentCost = c_f + c_v Q$$

$$c_f = c_s(1+n_s) + c_d d \qquad c_v = c_{vs} + c_{vd} d$$

$$ShipmentCost = \left[c_s(1+n_s) + c_d d\right] + \left[Q\left(c_{vs} + c_{vd} d\right)\right]$$

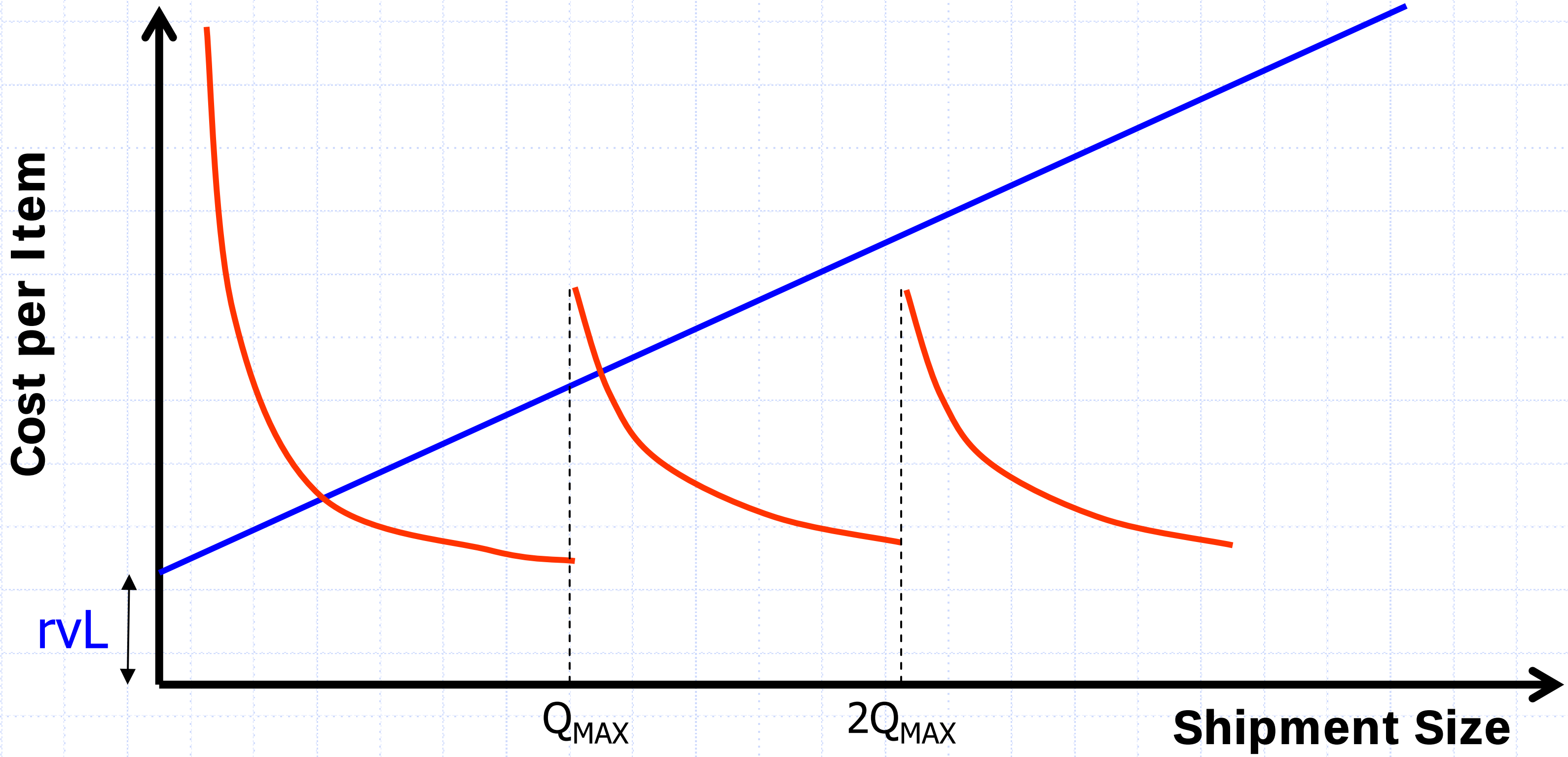
$$TransportCPI = c_s\left(\frac{1+n_s}{Q}\right) + c_d\left(\frac{d}{Q}\right) + c_{vs}$$

Nomenclature

- A= Fixed order cost ($/shipment)
- r= Inventory holding cost ($/yr)
- v= Purchase cost ($/item)
- Q = Shipment size (items)
- T = Shipment frequency (yr) = Q/D
- L = Lead time for transport (yr)
- c_f = Fixed transport cost ($/shipment)
- c_v = Variable transport cost (#/item)
- c_s = Fixed cost per stop ($/stop)
- c_d = Cost per distance ($/distance)
- c_{vd} = Marginal cost / item / distance
- c_{vs} = Marginal cost / item / stop
- n_s = Number of delivery stops

One to One System

$$TotalCPI = rv\left(\frac{T}{2}+L\right)+c_s\left(\frac{1+n_s}{Q}\right)+c_d\left(\frac{d}{Q}\right)+c_{vs}$$



Handling Costs

- Handling Costs ($/item)
  - Loading items into boxes, pallets, containers, etc.
  - If handled individually – linear with each item
  - If handled in batches – fixed & variable components
  - Generally subsumed w/in transportation (move) costs as long as $Q >> Q_{hMAX}$ (total shipment size is greater than pallet)

$$HandlingCost = c_{fh} + c_{vh} Q_h$$

$$MovementCost = c_f + \left(c_v + c_{vh} + \frac{c_{fh}}{Q_{hMAX}} \right) Q$$

$$Transport \,\&\, Handling = c_s \left(\frac{1 + n_s}{Q} \right) + c_d \left(\frac{d}{Q} \right) + \left[c_{vs} + c_{vh} + \frac{c_{fh}}{Q_{hMAX}} \right]$$

One to Many System

Single Distribution Center:
- Products originate from one origin
- Products are demanded at many destinations
- All destinations are within a specified Service Region
- Ignore inventory (service standards given)

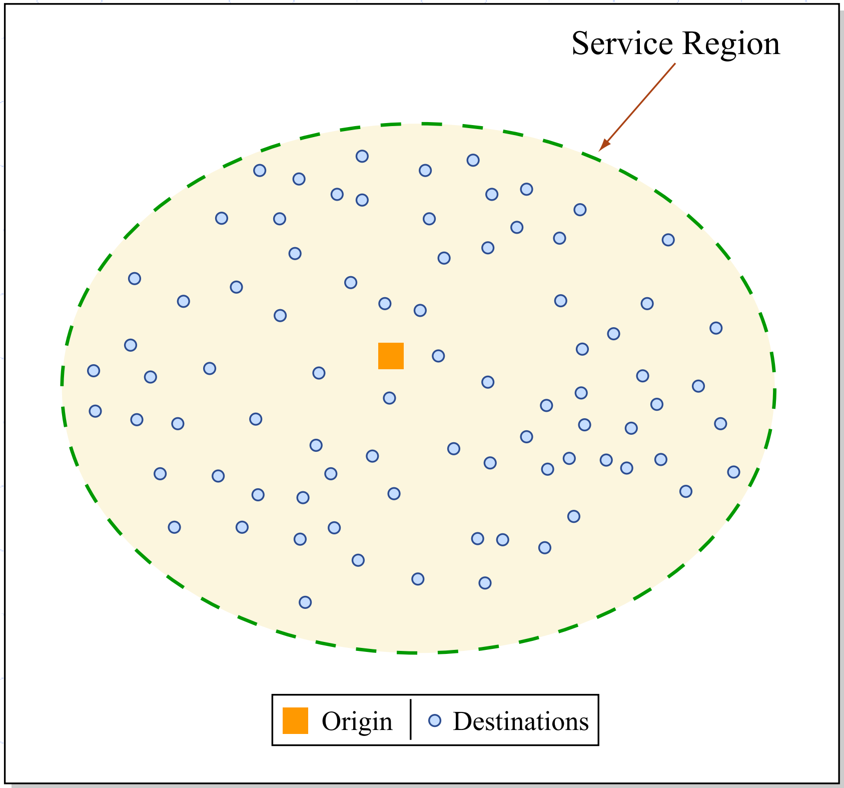


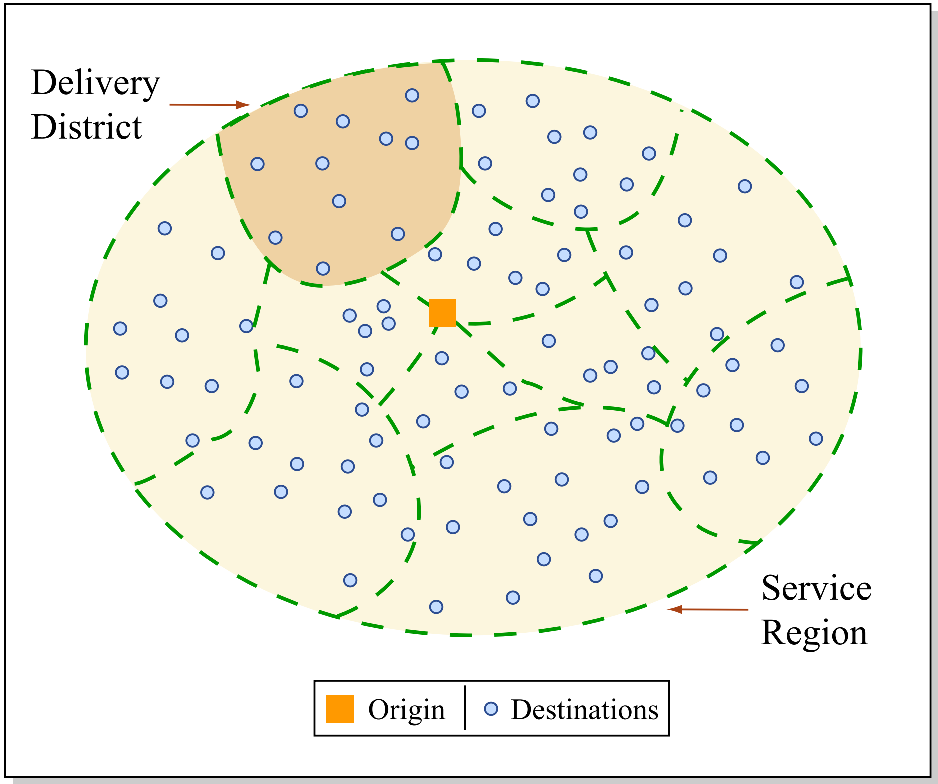
Figure by MIT OCW.
Based on Hernandez MLOG Thesis 2003

Assumptions:
- Vehicles are homogenous
- Same capacity, Q_{MAX}
- Fleet size is constant

One to Many System

Finding the estimated total distance:

- Divide the Service Region into Delivery Districts
- Estimate the distance required to service each district



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One to Many System

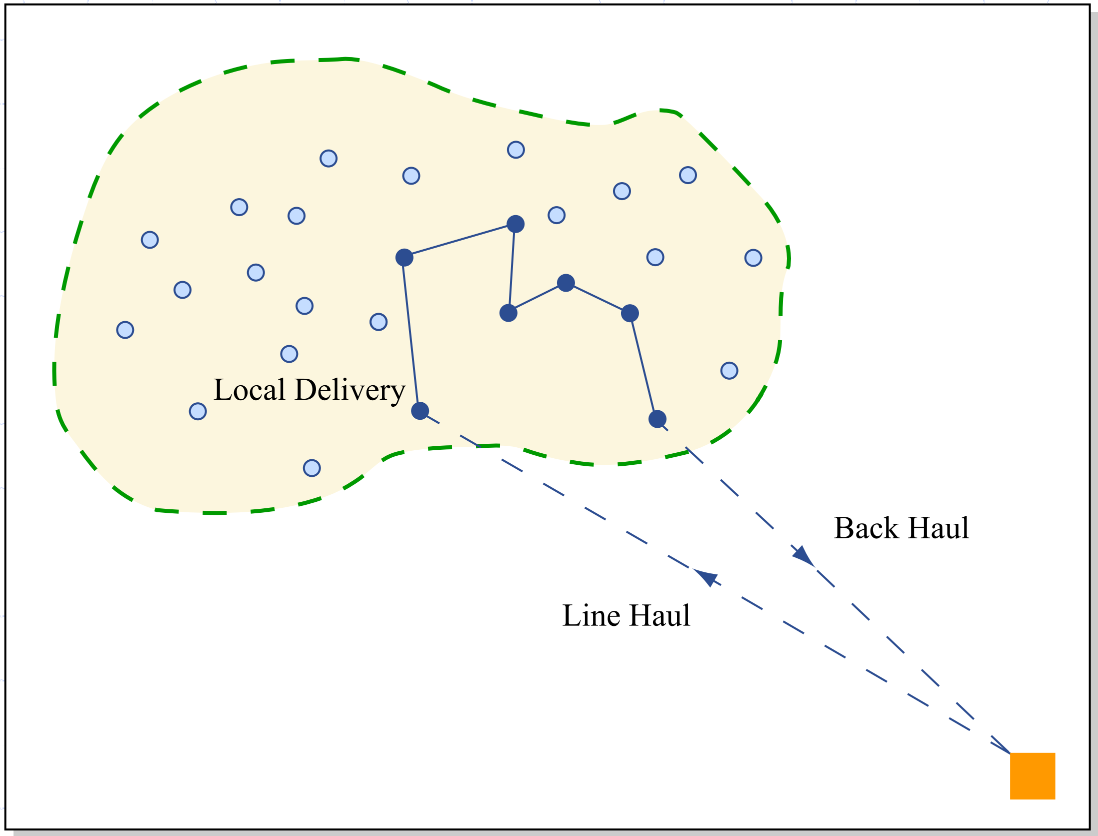

Figure by MIT OCW.

Route to serve a specific district:
- Line haul from origin to the 1st customer in the district
- Local delivery from 1st to last customer in the district
- Back haul (empty) from the last customer to the origin

Based on Hernandez MLOG Thesis 2003

An Aside: Routing & Scheduling

- Problem:
  - How do I route vehicle(s) from one or many origins to one or many destinations at a minimum cost?
  - A HUGE literature and area of research
- Traveling Salesman Problem / Vehicle Routing Problem
  - One origin, many destinations, sequential stops
  - Stops may require delivery & pick up
  - Vehicles have different capacity (capacitated)
  - Stops have time windows
  - Driving rules restricting length of tour, time, number of stops
- Discussed next lecture – Dr. Edgar Blanco

One to Many System

- Find the estimated distance for each tour, d_{TOUR}
  - Capacitated Vehicle Routing Problem (VRP)
  - Cluster-first, Route-second Heuristic

$$d_{TOUR} \approx 2d_{LineHaul} + d_{Local}$$

$d_{LineHaul}$ = Distance from origin to center of gravity (centroid) of delivery district

d_{Local} = Local delivery between c customers in district (TSP)

One to Many System

- What can we say about the expected TSP distance to cover n stops in district of area X?
  - Hard bound and some network specific estimates:

$$E\left[d_{TSP}\right] \leq 1.15\sqrt{nX}$$

$$E\left[d_{TSP}\right] \approx k\sqrt{nX}$$

For n>25 over Euclidean space, k=.7124

For grid (Manhattan Metric), k=.7650

Density, δ, number of stops per area

Average distance per stop, d_{stop}

$$\delta = \frac{n}{X}$$

$$d_{stop} = \frac{d_{TSP}}{n} = k \cdot \frac{\sqrt{nX}}{n} = \frac{k}{\sqrt{\delta}}$$

Source: Larson & Odoni Urban Operations Research 1981
http://web.mit.edu/urban_or_book/www/book/index.html, see section 3.87

One to Many System

- Length of local tours
  - Number of customer stops, c, times d_{stop} over entire region
  - Exploits property of TSP being sub-divided –
    - TSP of disjoint sub-regions ≥ TSP over entire region

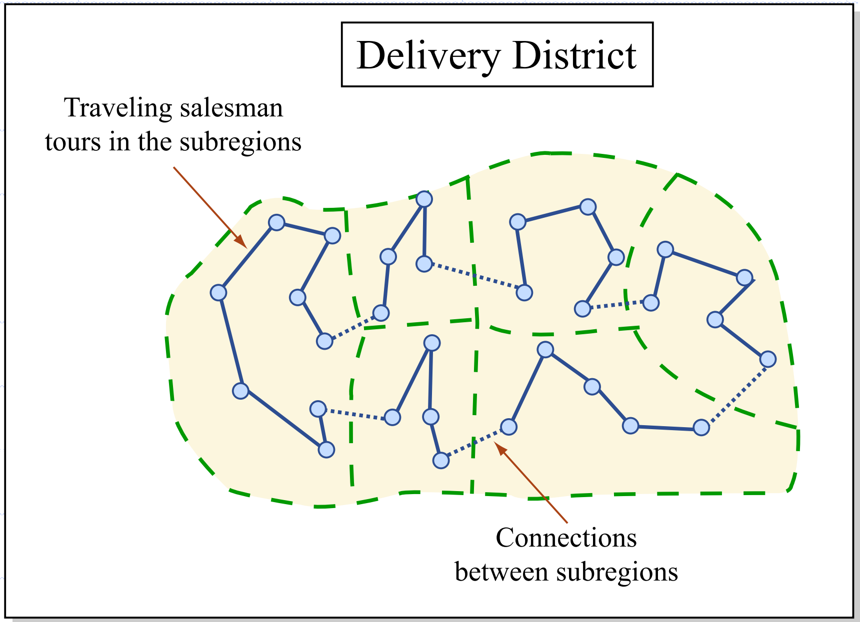

Figure by MIT OCW.

One to Many System

- Finding the total distance traveled on all, l, tours:

$$E\left[d_{TOUR}\right] = 2d_{LineHaul} + \frac{ck}{\sqrt{\delta}}$$

$$E\left[d_{AllTours}\right] = lE\left[d_{TOUR}\right] = 2ld_{LineHaul} + \frac{nk}{\sqrt{\delta}}$$

- Minimize number of tours by maximizing vehicle capacity

$$l = \left[\frac{D}{Q_{MAX}}\right]^{+}$$

$$E\left[d_{AllTours}\right] = 2\left[\frac{D}{Q_{MAX}}\right]^{+} d_{LineHaul} + \frac{nk}{\sqrt{\delta}}$$

$[x]^{+}$ is lowest integer value greater than x – a step function

Estimate this with continuous function:

$E([x]^{+}) \sim E(x) + 1/2$

One to Many System

- So that expected distance is:

$$E\left[d_{AllTours}\right] = 2\left[\frac{E\left[D\right]}{Q_{MAX}} + \frac{1}{2}\right] d_{LineHaul} + \frac{E\left[n\right]k}{\sqrt{\delta}}$$

- Note that if each delivery district has a different density, then:

$$E\left[d_{AllTours}\right] = 2\sum_i \left[\frac{E\left[D_i\right]}{Q_{MAX}} + \frac{1}{2}\right] d_{LineHaul_i} + k\sum_i \frac{E\left[n_i\right]}{\sqrt{\delta_i}}$$

- For identical districts, the transportation cost becomes:

$$TransportCost = c_s\left[E\left[n\right] + \frac{E\left[D\right]}{Q_{MAX}} + \frac{1}{2}\right] + c_d\left(2\left[\frac{E\left[D\right]}{Q_{MAX}} + \frac{1}{2}\right] d_{LineHaul} + \frac{E\left[n\right]k}{\sqrt{\delta}}\right) + c_{vs}E\left[D\right]$$

One to Many System

- Fleet Size
  - Find minimum number of vehicles required, M
  - Base on, W, amount of required work time
    - t_w = available worktime for each vehicle per period
    - s = average vehicle speed
    - l = number of shipments per period
    - t_l =loading time per shipment
    - t_s = unloading time per stop

$$Mt_w \geq W = \frac{d_{AllTours}}{s} + lt_l + nt_s$$

$$W = \left(\frac{2d_{LineHaul}}{s} + t_l\right)\left[\frac{E[D]}{Q_{MAX}} + \frac{1}{2}\right] + E[n]\left(\frac{k}{s\sqrt{\delta}} + t_s\right)$$

One to Many System

- Note that W is a linear combination of two random variables, n and D

$$E[aX + bY] = aE[X] + bE[Y]$$

$$Var[aX + bY] = a^2 Var[X] + b^2 Var[Y] + 2abCov[X, Y]$$

- Substituting in, we can find E[W] and Var[W]

$$a = \left(\frac{2d_{LineHaul}}{s} + t_l\right)\left[\frac{1}{Q_{MAX}}\right]$$

$$b = \left(\frac{k}{s\sqrt{\delta}} + t_s\right)$$

Given a service level, CSL

$P[W<Mt_w]=CSL$ Thus,

$M= (E[W] + k(CSL) StDev[W])/t_w$

Questions?