Transport 4: Transshipment

- FTL $\Rightarrow q = q_{\max}$, while TL $\Rightarrow q \leq q_{\max}$
- As a result, FTL has two very useful features:
  1. Most TL shipments should be close to FTL
     - Not a good long-term strategy to ship half-empty trucks
     - If necessary, aggregate with other shipments to make it FTL
  2. Monetary transport weights (w) and inventory cost (*IC*) are independent of NF location
     - Only transport cost (*TC*) needed for location analysis
     - Unlike TL and LTL, which require *TLC*

Ex: FTL vs Interval Constraint

- On average, 200 tons of components are shipped 750 miles from your fabrication plant to your assembly plant each year. The components are produced and consumed at a constant rate throughout the year. Currently, full truckloads of the material are shipped. What would be the impact on total annual logistics costs if TL shipments were made every two weeks? The revenue per loaded truck-mile is \$2.00; a truck's cubic and weight capacities are 3,000 ft^3 and 24 tons, respectively; each ton of the material is valued at \$5,000 and has a density of 10 lb per ft^3; the material loses 30% of its value after 18 months; and in-transit inventory costs can be ignored.

$$f = 200, \quad d = 750, \quad \alpha = \frac{1}{2} + \frac{1}{2} = 1, \quad r_{TL} = 2, \quad K_{cu} = 3000, \quad K_{wt} = 24, \quad v = 5000, \quad s = 10$$

$$h_{\text{obs}} = \frac{x_h}{t_h} = \frac{0.3}{1.5} = 0.2 \Rightarrow h = 0.05 + 0.06 + 0.2 = 0.31, \quad q_{FTL} = q_{\max} = \min\left\{K_{wt}, \frac{sK_{cu}}{2000}\right\} = 15$$

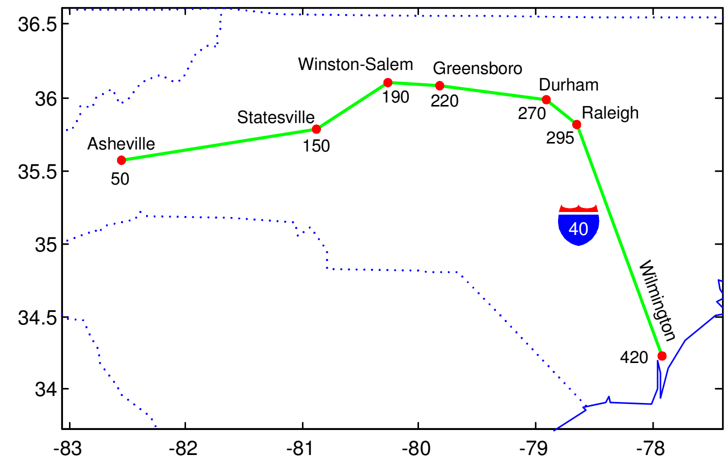
$$n_{FTL} = \frac{f}{q_{FTL}} = 13.33, TLC_{FTL} = n_{FTL} r_{TL} d + \alpha v h q_{FTL} = \$43,250, \quad \text{2-wk TL} \Rightarrow \text{LTL not considered}$$

$$t_{\max} = \frac{2(7)}{365.25} \text{ yr/TL} \Rightarrow n_{\min} = \frac{1}{t_{\max}} = 26.09 \text{ TL/yr}, \quad q_{2\text{wk}} = \frac{f}{\max\{n_{\text{FTL}}, n_{\min}\}} = 7.67 \text{ ton/TL}$$

$$TLC_{2\text{wk}} = n_{\min} r_{TL} d + \alpha v h q_{2\text{wk}} = \$51,016 \quad \Rightarrow \Delta TLC = TLC_{2\text{wk}} - TLC_{FTL} = \$7,766 \text{ per year increase}$$

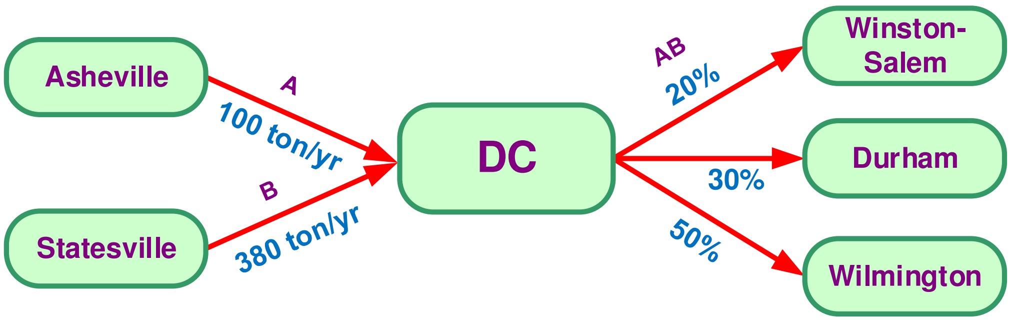
Ex: FTL Location

- Where should a DC be located in order to minimize transportation costs, given:



1. FTLs containing mix of products A and B shipped P2P from DC to customers in Winston-Salem, Durham, and Wilmington
2. Each customer receives 20, 30, and 50% of total demand
3. 100 tons/yr of A shipped FTL P2P to DC from supplier in Asheville
4. 380 tons/yr of B shipped FTL P2P to DC from Statesville
5. Each carton of A weighs 30 lb, and occupies 10 ft^3
6. Each carton of B weighs 120 lb, and occupies 4 ft^3
7. Revenue per loaded truck-mile is \$2
8. Each truck's cubic and weight capacity is 2,750 ft^3 and 25 tons, respectively

Ex: FTL Location



$$\underset{(\$/\text{yr})}{TC} = \sum \underset{(\$/\text{mi-yr})}{w_i} \times \underset{(\text{mi})}{d_i}$$

$$\underset{(\$/\text{mi-yr})}{w_i} = \underset{(\text{ton/yr})}{f_i} \times \underset{(\$/\text{ton-mi})}{r_{FTL,i}} = \underset{(\text{TL/yr})}{n_i} \times \underset{(\$/\text{TL-mi})}{r_i}$$

$$\underset{(\$/\text{ton-mi})}{r_{FTL,i}} = \frac{r}{q_{\max}}, \quad n = \frac{f}{q_{\max}}$$

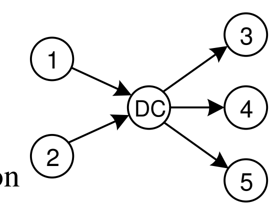
$$r = \$2/\text{TL-mi}, \quad f_{agg} = f_A + f_B = 100 + 380 = 480 \text{ ton/yr}, \quad s_{agg} = \frac{f_{agg}}{\frac{f_A}{s_A} + \frac{f_B}{s_B}} = \frac{480}{\frac{100}{3} + \frac{380}{30}} = 10.4348 \text{ lb/ft}^3, \quad q_{\max} = \left\{25, \frac{10.4348(2750)}{2000}\right\} = 14.3478$$

$$s_1 = \frac{30}{10} = 3 \text{ lb/ft}^3, \; q_{\max} = \min\left\{25, \frac{3(2750)}{2000}\right\} = 4.125 \text{ ton}$$

$$f_1 = 100, \; n_1 = \frac{100}{4.125} = 24.24, \; w_1 = 24.24(2) = 48.48$$

$$s_2 = \frac{120}{4} = 30 \text{ lb/ft}^3, \; q_{\max} = \min\left\{25, \frac{30(2750)}{2000}\right\} = 25 \text{ ton}$$

$$f_2 = 380, \; n_2 = \frac{380}{25} = 15.2, \; w_2 = 15.2(2) = 30.4$$

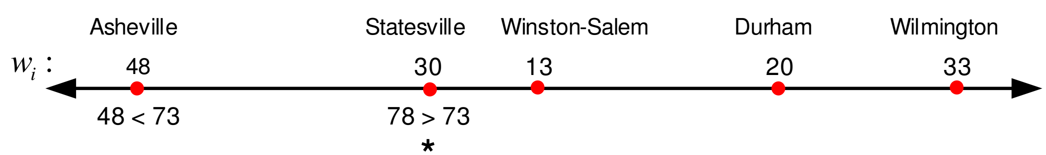


$$f_3 = 0.20 f_{agg} = 96, \; n_3 = \frac{96}{14.3478} = 6.69, \; w_3 = 6.69(2) = 13.38$$

$$f_4 = 0.30 f_{agg} = 144, \; n_4 = \frac{144}{14.3478} = 10.04, \; w_4 = 10.04(2) = 20.07$$

$$f_5 = 0.50 f_{agg} = 240, \; n_5 = \frac{240}{14.3478} = 16.73, \; w_5 = 16.73(2) = 33.45$$

$$W = 146, \quad \frac{W}{2} = 73$$



$$\text{(Montetary) Weight Losing:} \quad \Sigma w_{in} = 79 > \Sigma w_{out} = 67 \quad (\Sigma n_{in} = 39 > \Sigma n_{out} = 33)$$

$$\text{Physically Weight Unchanging (DC):} \quad \Sigma f_{in} = 480 = \Sigma f_{out} = 480$$

Ex: FTL Location

- (Extension) Include monthly outbound frequency constraint:
  - Outbound shipments must occur at least once each month

    (provides an implicit means of including inventory costs in location decision)

$$t_{\max} = \frac{1}{12}\text{ yr/TL} \quad \Rightarrow \quad n_{\min} = \frac{1}{t_{\max}} = 12\text{ TL/yr}$$

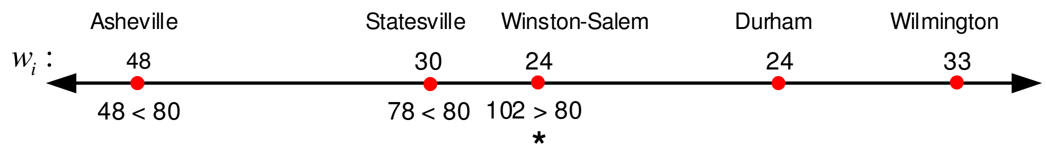
$$TC'_{FTL} = \max\left\{n, n_{\min}\right\} rd$$

$$n_3 = \max\left\{6.69, 12\right\} = 12, w_3 = 12(2) = 24$$

$$n_4 = \max\left\{10.04, 12\right\} = 12, w_4 = 12(2) = 24$$

$$n_5 = \max\left\{16.73, 12\right\} = 16.73, w_5 = 16.73(2) = 33.45$$

$W = 160,\quad \frac{W}{2} = 80$



$$\text{(Montetary) Weight Gaining:}\quad \Sigma w_{\text{in}} = 79 < \Sigma w_{\text{out}} = 81 \quad \left(\Sigma n_{\text{in}} = 39 < \Sigma n_{\text{out}} = 41\right)$$

$$\text{Physically Weight Unchanging (DC):}\quad \Sigma f_{\text{in}} = 480 = \Sigma f_{\text{out}} = 480$$

Location and Transport Costs

- Monetary weights *w* used for location are, in general, a function of the location of a NF
  - Distance *d* appears in optimal TL size formula
  - TC & IC functions of location $\Rightarrow$ Need to minimize TLC instead of TC
  - FTL (since size is fixed at max payload) results in only constant weights for location $\Rightarrow$ Need to only minimize TC since IC is constant in TLC

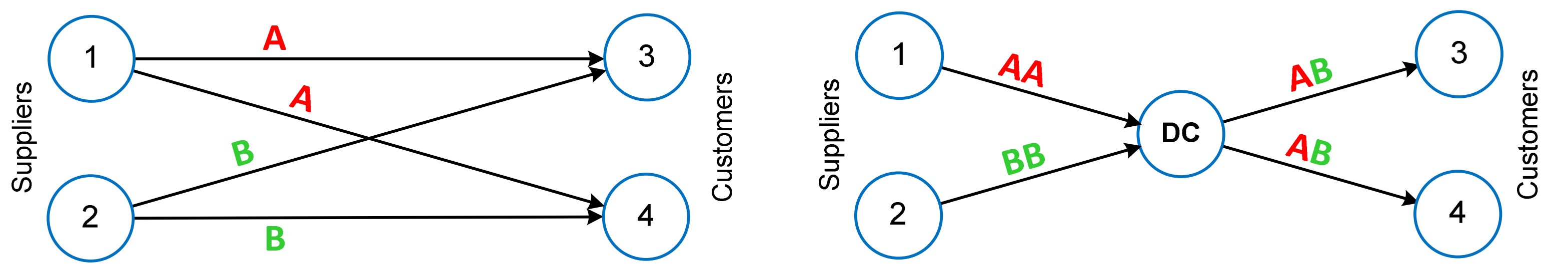
$$TLC_{TL}(\mathbf{x}) = \sum_{i=1}^{m} w_i(\mathbf{x}) d_i(\mathbf{x}) + \alpha v h q_i(\mathbf{x}) = \sum_{i=1}^{m} \frac{f_i}{q_i(\mathbf{x})} r d_i(\mathbf{x}) + \alpha v h\, q_i(\mathbf{x})$$

$$= \sum_{i=1}^{m} \frac{f_i}{\sqrt{\dfrac{f_i r d_i(\mathbf{x})}{\alpha v h}}} r d_i(\mathbf{x}) + \alpha v h \sqrt{\frac{f_i r d_i(\mathbf{x})}{\alpha v h}} = \sum_{i=1}^{m} \sqrt{f_i r d_i(\mathbf{x})} \left(\frac{1}{\sqrt{\alpha v h}} + \sqrt{\alpha v h} \right)$$

$$TLC_{FTL}(\mathbf{x}) = \sum_{i=1}^{m} \frac{f_i}{q_{\max}} r d_i(\mathbf{x}) + \alpha v h\, q_{\max} = \sum_{i=1}^{m} w_i\, d_i(\mathbf{x}) + \alpha v h\, q_{\max} = TC_{FTL}(\mathbf{x}) + \text{constant}$$

Transshipment

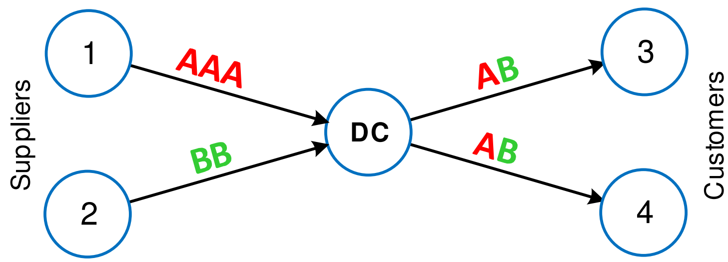
- *Direct*: P2P shipments from Suppliers to Customers



- *Transshipment*: use DC to consolidate outbound shipments
  - *Uncoordinated*: determine separately each optimal inbound and outbound shipment $\Rightarrow$ hold inventory at DC
  - *(Perfect) Cross-dock*: use single shipment interval for all inbound and outbound shipments $\Rightarrow$ no inventory at DC (non-perfect: only cross-dock a selected subset of shipments)

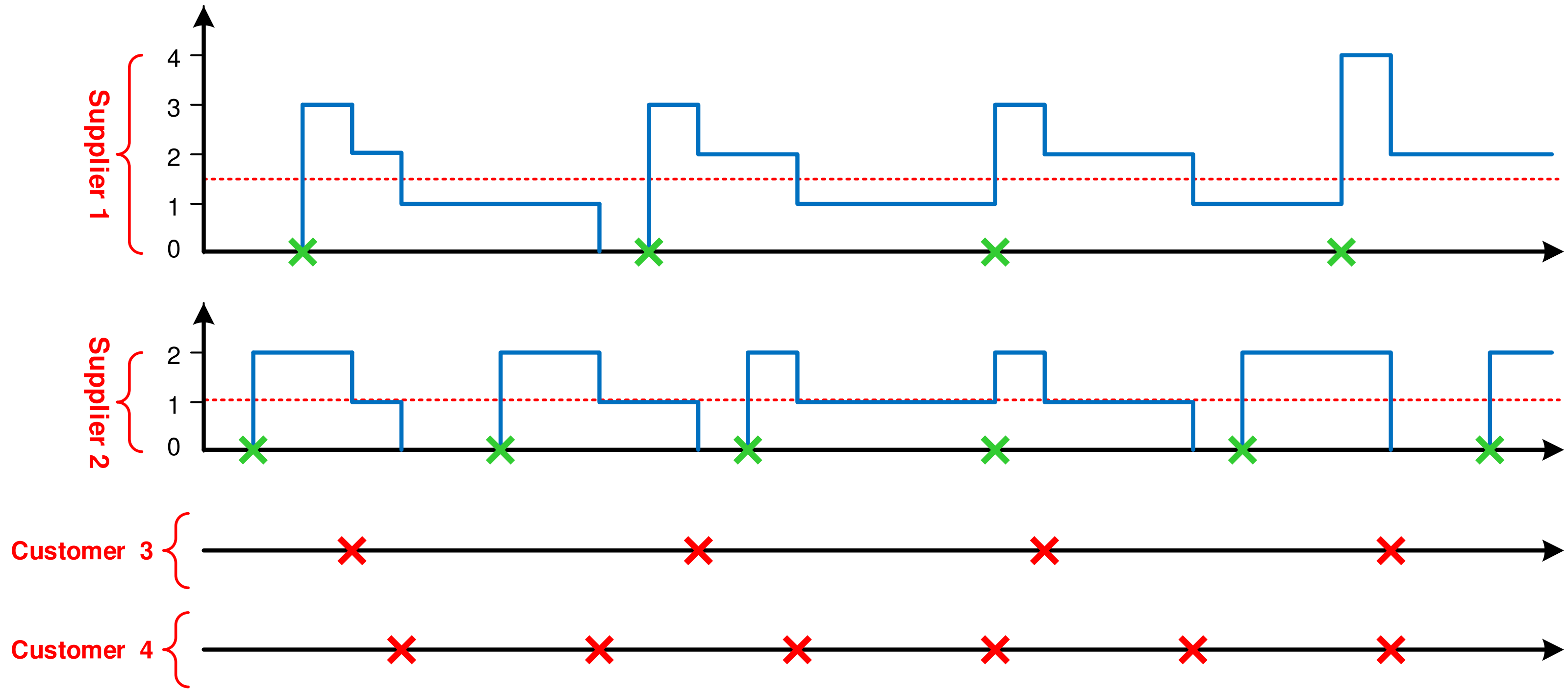
Uncoordinated Inventory

- Average in-transit inventory level at DC:



$$q_A^* = 3, \quad q_B^* = 2$$

$$\alpha = \begin{cases} \alpha_S + \frac{1}{2}, & \text{inbound} \\ 0 + \alpha_C, & \text{outbound} \end{cases}$$



$$1.55 \approx \frac{q_A^*}{2}$$

$$1.11 \approx \frac{q_B^*}{2}$$

TLC with Transshipment

- Uncoordinated: $TLC_i = TLC$ of supplier/customer i

$$q_i^* = \arg\min_q TLC_i(q)$$

$$TLC^* = \sum TLC_i\left(q_i^*\right)$$

- Cross-docking: $t = \dfrac{q}{f}$, shipment interval $\left(\Rightarrow q = ft\right)$

$$TLC_i(t) = \frac{c_0(t)}{t} + \alpha vhft \quad \left(\text{cf. } TLC_i(q) = \frac{f}{q}c_0(q) + \alpha vhq\right)$$

$$c_0(t) = \text{independent transport charge as function of } t$$

$$\alpha = \begin{cases} \alpha_S + 0, & \text{inbound} \\ 0 + \alpha_C, & \text{outbound} \end{cases}$$

$$t^* = \arg\min_t \sum TLC_i(t)$$

$$TLC^* = \sum TLC_i\left(t^*\right)$$

Ex: TLC Location with Transshipment

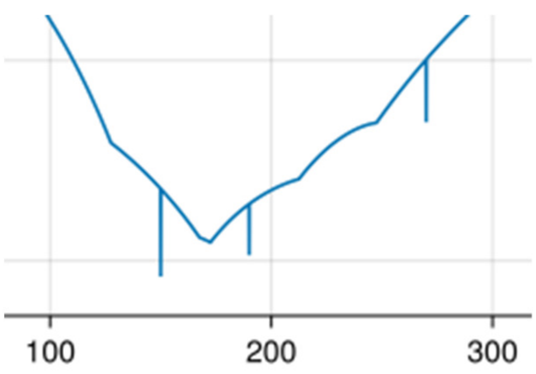
- Continuing with *Ex: FTL Location*:
  1. All transport TL (no LTL)
  2. Each carton of A valued at $300
  3. Each carton of B valued at $450
  4. Batch production, constant consumption
  5. Transshipments at the DC use either uncoordinated inventory (UC) or perfect cross-docking (XD)

$$\alpha = \begin{cases} \alpha_S + \frac{1}{2} = 0 + \frac{1}{2} = \frac{1}{2}, & \text{inbound} \\ 0 + \alpha_C = 0 + \frac{1}{2} = \frac{1}{2}, & \text{outbound} \end{cases}$$

$$v_1 = \frac{\text{unit value A}}{\left(\frac{\text{unit weight A}}{2000}\right)} = \frac{300}{\left(\frac{30}{2000}\right)}$$
$$= \$20,000/\text{ton}$$

- Where should the DC be located to minimize TLC?
- UC Result: Locate at 150 (Statesville) by plot inspection

Row	f	s	v	α	h	d	qmax	q°	TLC°	isLTL
	Float64	Float64	Float64	Float64	Float64	Int64	Float64	Float64	Float64	Bool
1	100.0	3.0	20000.0	0.5	0.3	100	4.125	2.58199	15491.9	false
2	380.0	30.0	7500.0	0.5	0.3	0	25.0	3.89872	4386.06	false
3	96.0	10.4348	10104.2	0.5	0.3	40	14.3478	2.25105	6823.49	false
4	144.0	10.4348	10104.2	0.5	0.3	120	14.3478	4.77519	14474.8	false
5	240.0	10.4348	10104.2	0.5	0.3	270	14.3478	9.24712	28030.3	false



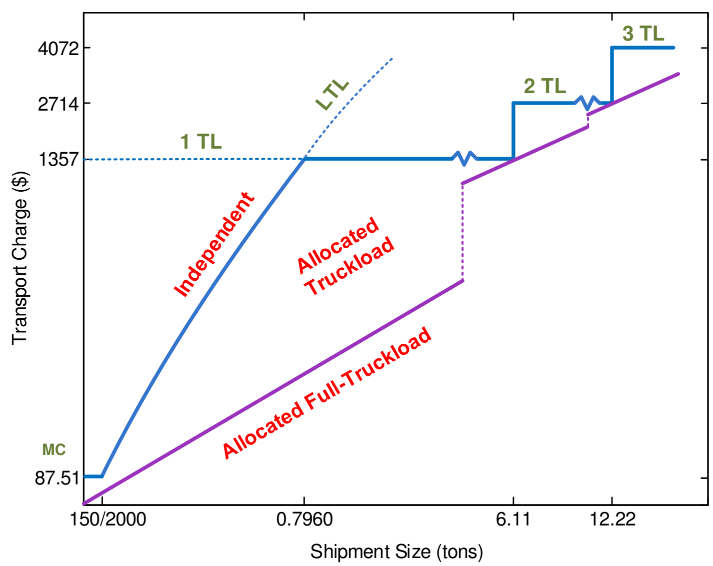
Ex: TLC Location with Transshipment

- **Problem:** Solution not realistic because both UC and XD shipments using only small portion of maximum TL payload; fixes:
  - Include LTL as a transport option (35 mi distance limit a problem)
  - Consider current XD solution as UB on TLC, use allocated FTL as LB

$$r_{FTL} = \frac{r_{TL}}{q_{\max}}$$

$$TLC_{AllocFTL}(q_{TL}^{*}) = \frac{f}{q_{TL}^{*}}\left(q_{TL}^{*} r_{FTL} d\right) + \alpha v h q_{TL}^{*}$$

$$= f\,\frac{r_{TL}}{q_{\max}} d + \alpha v h q_{TL}^{*}$$

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Uncooridinated          = 69,206.63 ($/yr)
Perfect Cross-Docking   = 55,539.18 ($/yr)
Allocated FTL           = 44,594.80 ($/yr)
```

Row	f	qmax	q°	TLC°	qXD	TLC_XD	TLC_AFTL
	Float64	Float64	Float64	Float64	Float64	Float64	Float64
1	100.0	4.125	2.58199	15491.9	3.81713	5239.54	4848.48
2	380.0	25.0	3.89872	4386.06	14.5051	0.0	0.0
3	96.0	14.3478	2.25105	6823.49	3.66444	7649.74	6089.19
4	144.0	14.3478	4.77519	14474.8	5.49666	14618.3	10739.6
5	240.0	14.3478	9.24712	28030.3	9.1611	28031.6	22917.5

Ex: Direct vs Transhipment

- 3 different products supplied to 4 customers
- Compare:
  1. Direct shipments
  2. Uncoordinated at existing DC in Memphis
  3. Cross-docking at DC in Memphis
- Optimal DC location:
  - Denver for UC ($754K)
  - Kansas for XD ($598K)

Row	f	s	α	v	d	qmax	q°	TLC°	isLTL	t
	Float64	Int64	Float64	Int64	Float64	Float64	Float64	Float64	Bool	Float64
1	100.0	32	0.5	50000	2641.83	25.0	1.99905	1.14292e5	true	7.30154
2	15.0	3	0.5	25000	3043.26	4.125	4.125	43786.7	false	100.444
3	60.0	12	0.5	10000	2057.81	16.5	14.5131	43539.3	false	88.3485
4	175.0	32	0.5	50000	2346.59	25.0	3.10225	1.77379e5	true	6.47485
5	26.25	3	0.5	25000	2136.29	4.125	4.125	50256.0	false	57.3964
6	105.0	12	0.5	10000	906.461	16.5	12.7424	38227.2	false	44.3253
7	125.0	32	0.5	50000	1709.51	25.0	2.07247	1.17048e5	true	6.05576
8	18.75	3	0.5	25000	1867.03	4.125	4.125	37184.9	false	80.355
9	75.0	12	0.5	10000	957.05	16.5	11.0657	33197.2	false	53.8901
10	100.0	32	0.5	50000	626.061	25.0	1.2388	66432.0	true	4.52473
11	15.0	3	0.5	25000	1295.17	4.125	3.641	27307.5	false	88.6583
12	60.0	12	0.5	10000	1327.78	16.5	11.6579	34973.7	false	70.9675

Row	Method	TLC	t̄	LTL
	String	Int64	Float64	Int64
1	Direct Shipments	783623	50.7285	4
2	Uncoord Inv at DC	797779	18.6735	0
3	Cross-Docking at DC	657532	18.2625	0

TLC and Location

- TLC should include all logistics-related costs

  $\Rightarrow$ TLC can be used as sole objective for network design (incl. location)

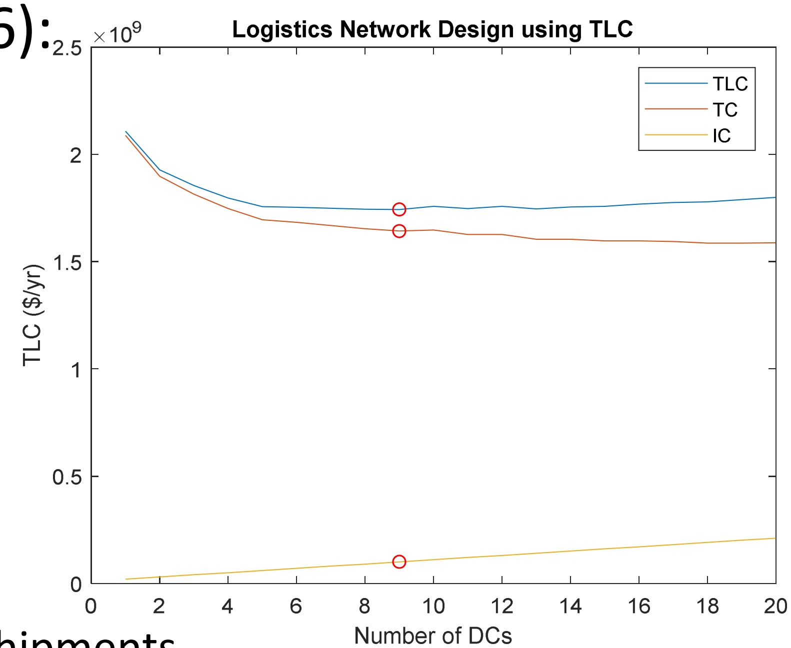
- Facility fixed costs, two options:
  1. Use non-transport-related facility costs (mix of top-down and bottom-up) to estimate fixed costs via linear regression
  2. For DCs, might assume public warehouses to be used for all DCs
     $\Rightarrow$ Pay only for time each unit spends in WH $\Rightarrow$ No fixed cost at DC

- Transport fixed costs:
  – Costs that are independent of shipment size (e.g., $/mi vs. $/ton-mi)
    - Costs that make it worthwhile to incur the inventory cost associated with larger shipment sizes in order to spread out the fixed cost

  – Main transport fixed cost is the indivisible labor cost for a human driver
    - Why many logistics networks (e.g., Walmart, Lowes) designed for all FTL transport

Ex: Optimal Number DCs for Lowe's

- Example of logistics network design using TLC
- Lowe's logistics network (2016):
  - Regional DCs (15)
  - Costal holding facilities
  - Appliance DCs and Flatbed DCs
  - Transloading facilities

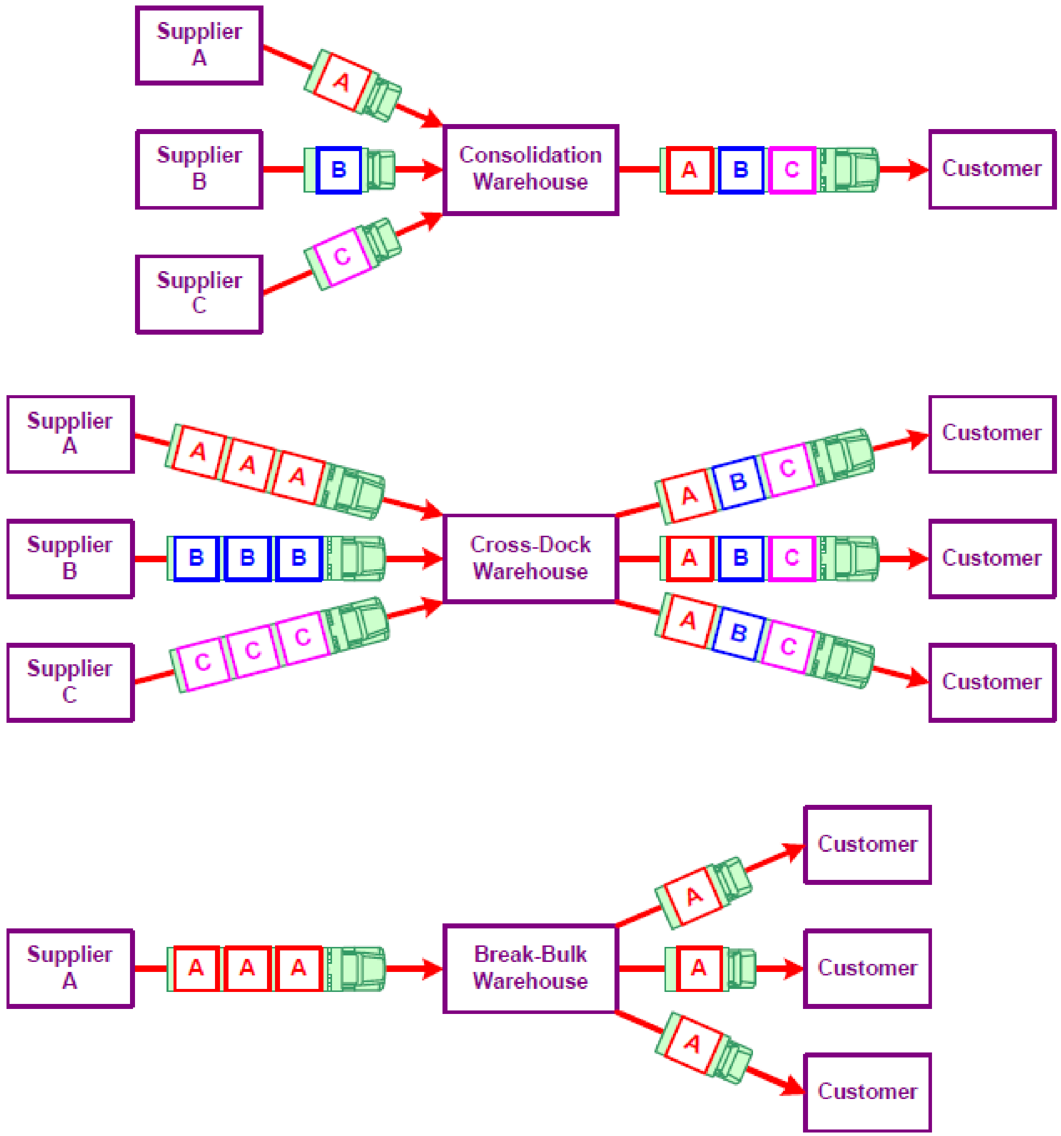


- Modeling approach:
  - Focus only on Regional DCs
  - Mix of top-down (COGS) and bottom-up (typical load/TL parameters)
  - FTL for all inbound and outbound shipments
  - ALA used to determine TC for given number of DCs
  - $IC = \alpha v h q_{\max} \times$ (number of suppliers $\times$ number of DCs + number stores)
  - Assume uncoordinated DC inventory, no cross-docking
  - Ignoring max DC-to-store distance constraints, consolidation, etc.
- Determined 9 DCs min TLC (15 DCs $\Rightarrow$ 0.87% increase in TLC)

Warehousing

- *Warehousing* are the activities involved in the design and operation of warehouses
- A *warehouse* is the point in the supply chain where raw materials, work-in-process (WIP), or finished goods are stored for varying lengths of time.
- Warehouses can be used to add value to a supply chain in two basic ways:
  1. Storage. Allows product to be available where and when its needed.
  2. Transport Economies. Allows product to be collected, sorted, and distributed efficiently.
- A *public warehouse* is a business that rents storage space to other firms on a month-to-month basis. They are often used by firms to supplement their own *private warehouses*.

Types of Warehouses



Warehouse Automation

- Historically, warehouse automation has been a craft industry, resulting highly customized, one-off, high-cost solutions
- To survive, need to
  - adapt mass-market, consumer-oriented technologies in order to realize to economies of scale
  - replace mechanical complexity with software complexity
- How much can be spent for automated equipment to replace one material handler:

$$\$45,432\left(\frac{1-1.017^{-5}}{1-1.017^{-1}}\right)=\$45,432\left(4.83\right)=\$219,692$$

  - \$45,432: median moving machine operator annual wage + benefits
  - 1.7% average real interest rate 2005-2009 (real = nominal – inflation)
  - 5-year service life with no salvage (service life for Custom Software)

KIVA Mobile-Robotic Fulfillment System

- Goods-to-man order picking and fulfillment system
- Multi-agent-based control
  - Developed by Peter Wurman, former NCSU CSC professor
- Kiva (founded 2003) now called Amazon Robotics
  - purchased by Amazon in 2012 for $775 million

Mick Mountz, Peter Wurman and Raffaello D'Andrea (left to right), creators of Kiva Systems. | Credit: National Inventors Hall of Fame