Ex 11: 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 ft³ and 24 tons, respectively; each ton of the material is valued at $5,000 and has a density of 10 lb per ft³; the material loses 30% of its value after 18 months; and in-transit inventory costs can be ignored.

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

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

$$n_{FTL} = \frac{f}{q_{FTL}} = 13.33, TLC_{FTL} = n_{FTL} r_{TL} d + \alpha v h q_{FTL} = 43,250, \quad \text{2-wk TL} \Rightarrow \text{LTL not considered}$$
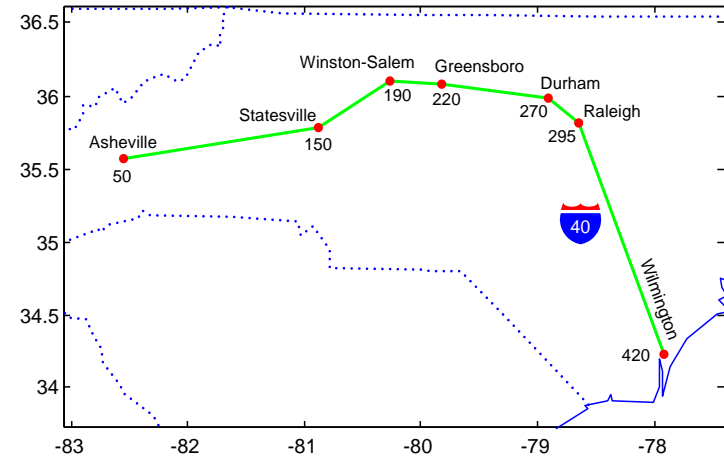
$$t_{\max} = \frac{2 \cdot 7}{365.25} \Rightarrow n_{\min} = 26.09, \quad q_{2\text{wk}} = \frac{f}{n_{\min}} = 7.67, \quad TLC_{2\text{wk}} = n_{\min} r_{TL} d + \alpha v h q_{2\text{wk}} = 51,016$$

$$\Delta TLC = TLC_{2\text{wk}} - TLC_{FTL} = \$7,766 \text{ per year increase with two-week interval constraint}$$
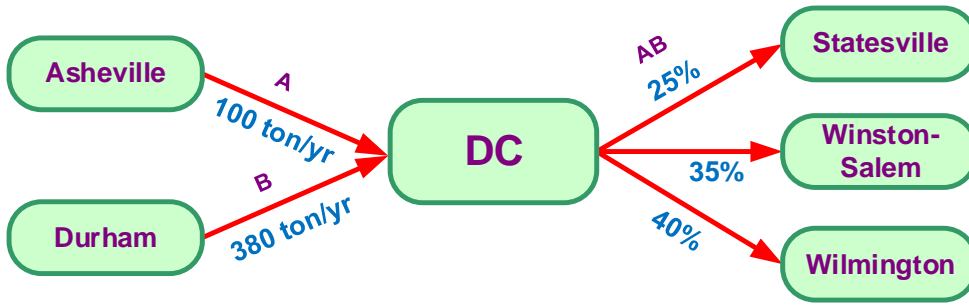
Ex 12: FTL Location

- 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 12: FTL Location

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

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

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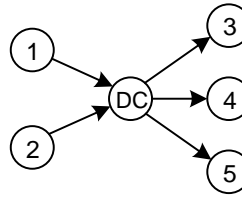
$r = \$2/\text{TL-mi}, \quad f_{\text{agg}} = f_A + f_B = 100 + 380 = 480 \text{ ton/yr}, \quad s_{\text{agg}} = \dfrac{f_{\text{agg}}}{\dfrac{f_A}{s_A} + \dfrac{f_B}{s_B}} = \dfrac{480}{\dfrac{100}{3} + \dfrac{380}{30}} = 10.4348 \text{ lb/ft}^3, \quad q_{\max} = \left\{ 25, \dfrac{10.4348(2750)}{2000}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

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

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

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

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

$s_2 = \dfrac{120}{4} = 30 \text{ lb/ft}^3, q_{\max} = \min\left\{ 25, \dfrac{30(2750)}{2000} \right\} = 25 \text{ ton}$
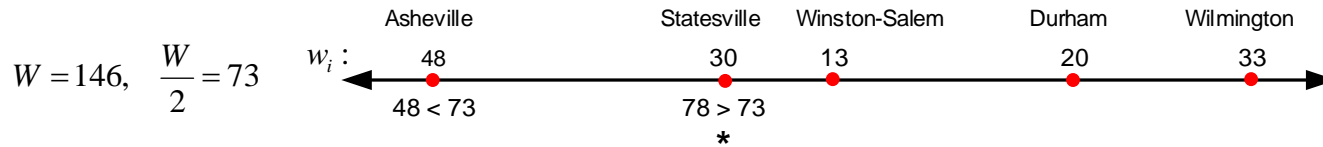
$f_5 = 0.50 f_{\text{agg}} = 240, n_5 = \dfrac{240}{14.3478} = 16.73, w_5 = 16.73(2) = 33.45$

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

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

w_i:	Asheville		Statesville	Winston-Salem		Durham	Wilmington
	48		30	13		20	33

48 < 73

78 > 73
*

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

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

Ex 12: FTL Location

- Include monthly outbound frequency constraint:
  - Outbound shipments must occur at least once each month
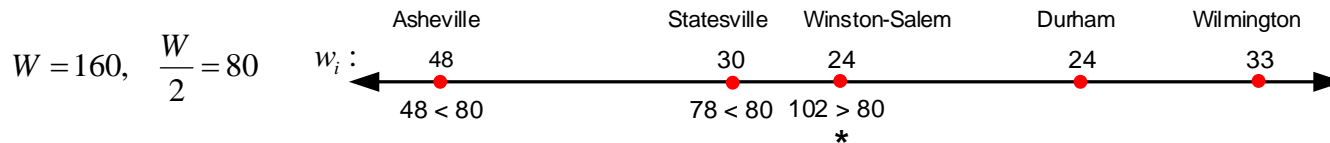 - Implicit means of including inventory costs in location decision

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

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

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

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

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

	Asheville		Statesville	Winston-Salem	Durham	Wilmington
$W = 160, \ \frac{W}{2} = 80 \quad w_i:$	48		30	24	24	33

48 < 80   78 < 80   102 > 80
                            *

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

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

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

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

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

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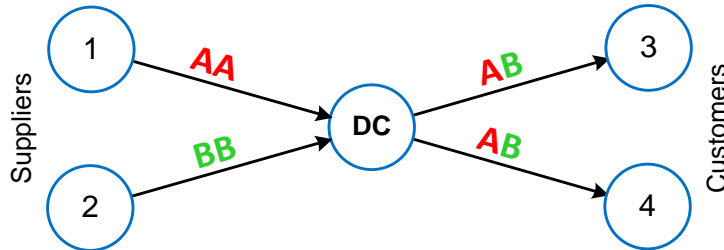
Transshipment

- *Direct*: P2P shipments from Suppliers to Customers
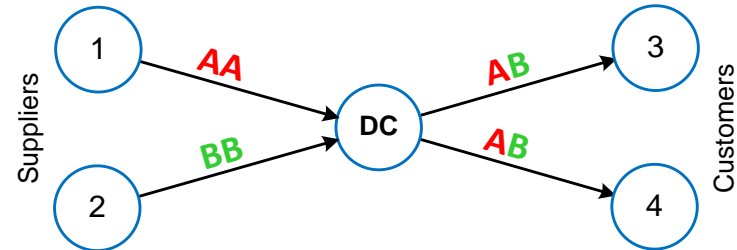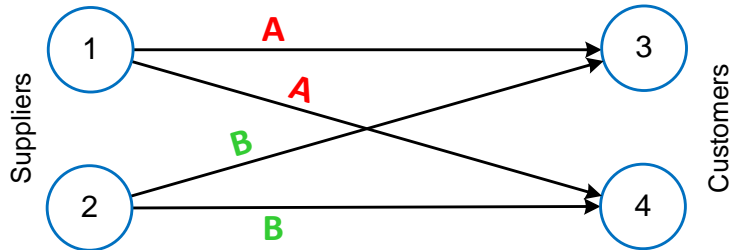
- *Transshipment*: use DC to consolidate outbound shipments

  – *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 (usually only cross-dock a selected subset of shipments)
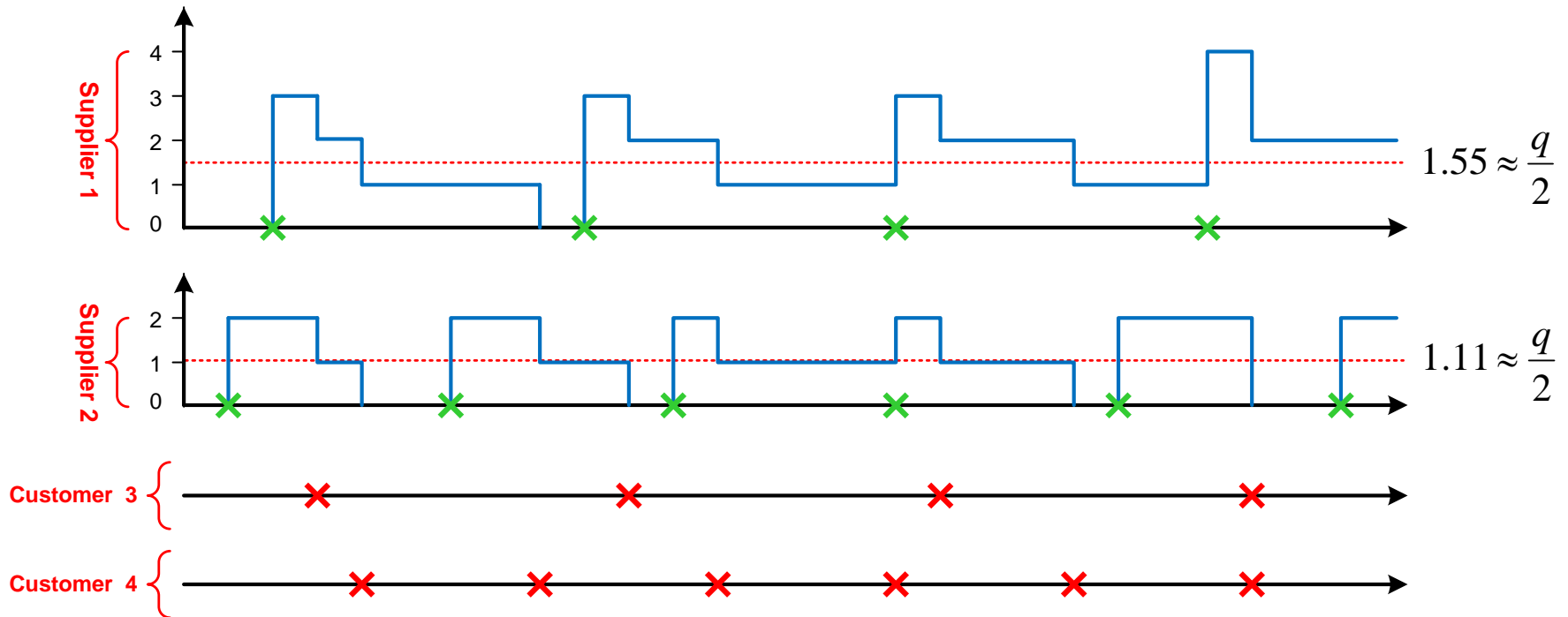
Uncoordinated Inventory

- Average pipeline inventory level at DC:

$$\alpha = \alpha_O + \alpha_D$$

$$= \begin{cases} \alpha_O + \dfrac{1}{2}, & \text{inbound} \\ 0 + \alpha_D, & \text{outbound} \end{cases}$$

$$1.55 \approx \frac{q}{2}$$

$$1.11 \approx \frac{q}{2}$$

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: $t = \dfrac{q}{f}, \quad$ shipment interval

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

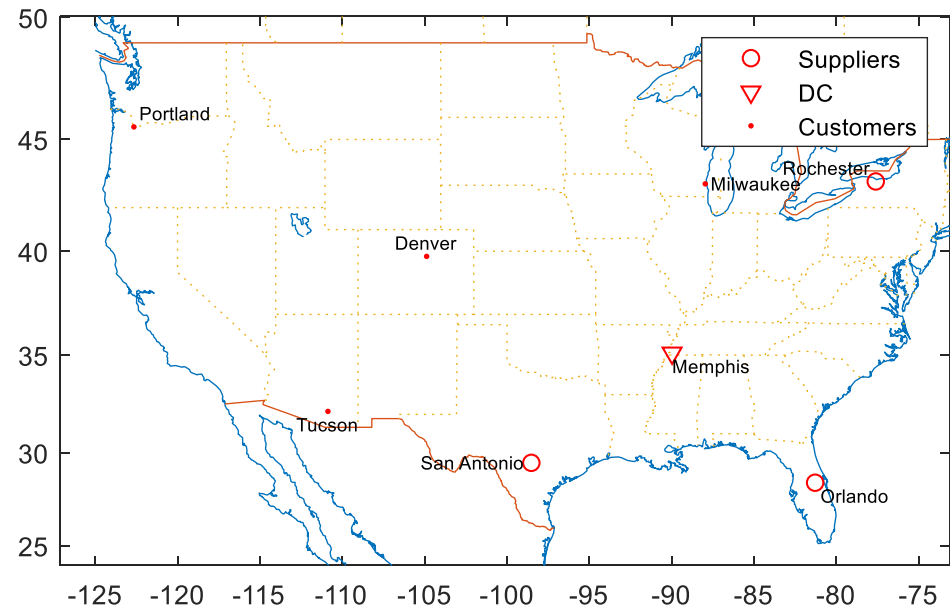$c_0(t) =$ independent transport charge as function of t

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

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

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

Ex 13: 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 Memphis
  4. Uncoordinated at optimal DC location
  5. Cross-docking at optimal location


```
Transshipment Example:          TLC        t      LTL
-------------------------------:--------------------------
                       Direct:  783,139.06  50.71   4
     Uncoordinated at Memphis:  797,281.81  18.67   0
      Cross-Docking at Memphis: 634,470.88  18.26   0
Uncoordinated at Optimal Location: 754,102.09  15.65   0
Cross-Docking at Optimal Location: 598,052.01  18.26   0
```

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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 14: 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
  - $IC = \alpha vh q_{max} \times$ (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.

Logistics Network Design using TLC
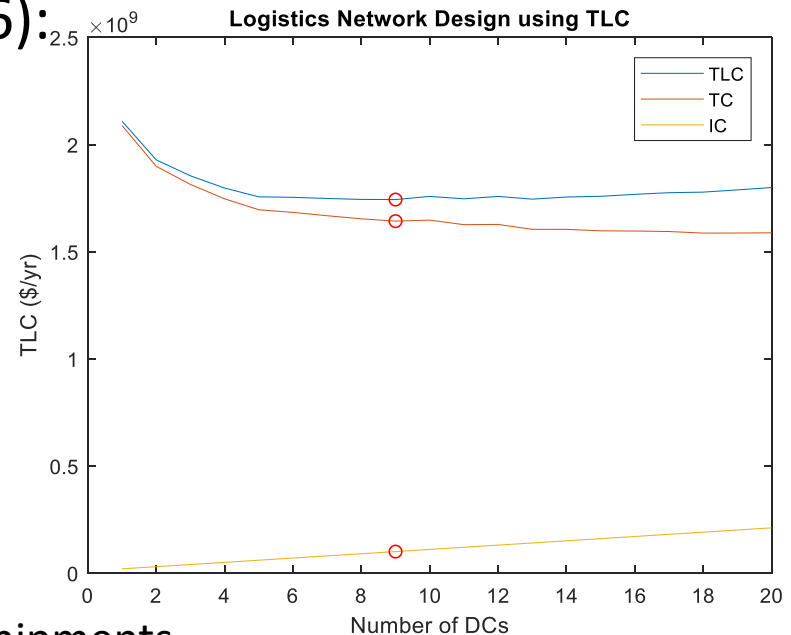
- Determined 9 DCs min TLC (15 DCs $\Rightarrow$ 0.87% increase in TLC)