Introduction to Supply Chain Engineering

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Action Items

- Suggested reading
  - Ghiani et al. Ch. 1

About Me

- BSIE Jordan University of Science and Technology
- MSIE Jordan University of Science and Technology
- PhD Industrial & Systems Engineering, Kansas State University
- Research
  - Optimization
- Dissertation: Optimization of Lignocellulosic Biomass-to-Biofuel Supply Chains Considering Mobile Pelleting and Farmer Choices
- Teaching:
  - Facilities planning
  - Strategic planning
  - Game Theory & Decision Analysis
  - Logistics
  - Engineering Statistics 2

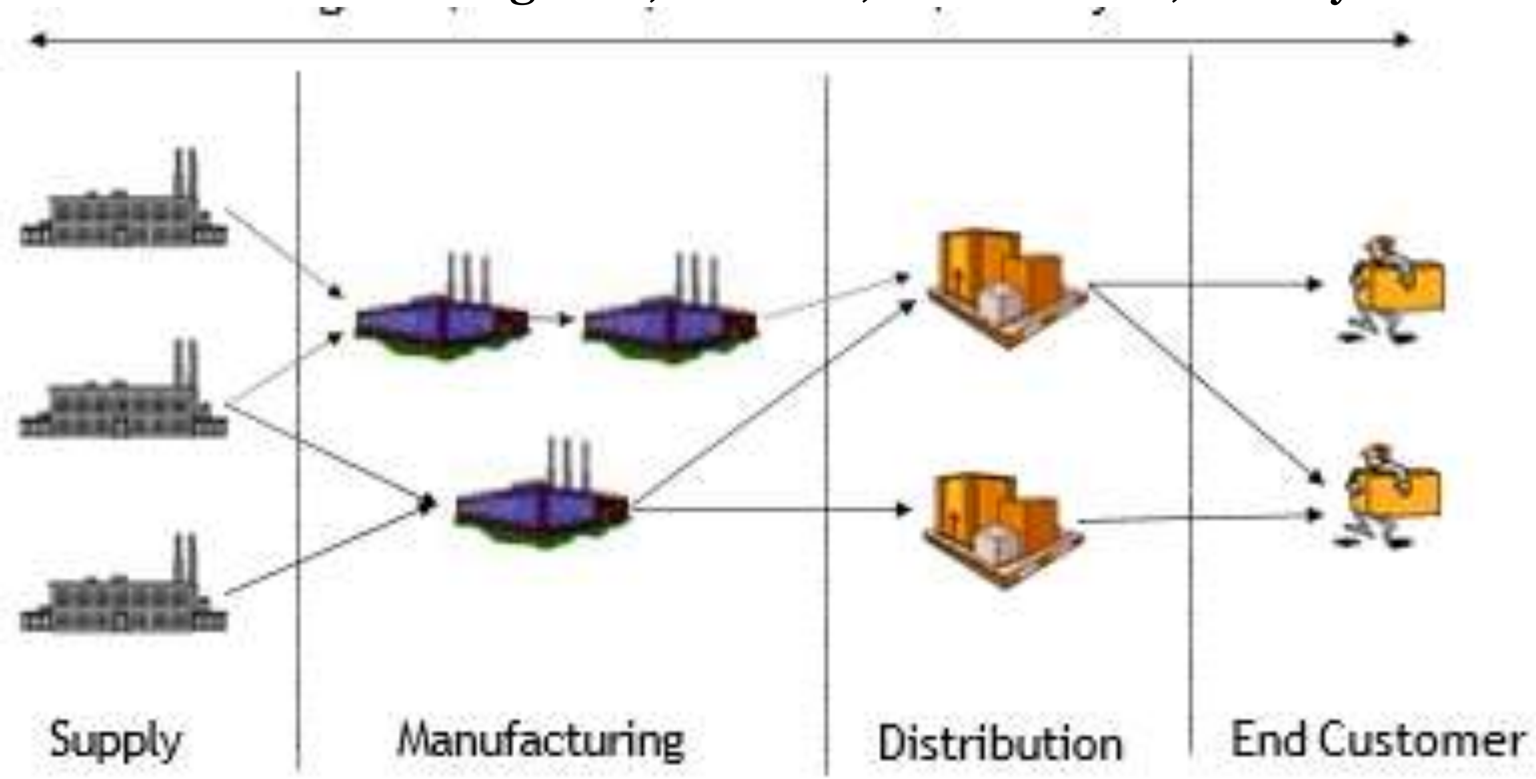
Course Overview

- Intro, terminology
- Modes and Mode choice
- Short-haul transport: single vehicle
  - Shortest path, traveling salesperson problems
- Short-haul transport: multiple vehicle
  - Bin packing, vehicle routing problems
- Long-haul transport
  - Minimum cost flow, fixed charge network problems
- Facility location

What is a Supply Chain (Network)?

•System of organizations and processes that interact to convert raw inputs into products or services for customers.

goods, services, information, money



Supply Network Organization

- Within your firm
  - Design and production departments
  - Logistics/traffic management/transportation departments
  - Sales and marketing departments
  - Finance department
- Other firms
  - Suppliers
  - Suppliers' suppliers (and so on!)
  - Customers
  - Customers' customers (and so on!)
  - Logistics service providers (carriers, 3PLs, forwarders, brokers, etc.)

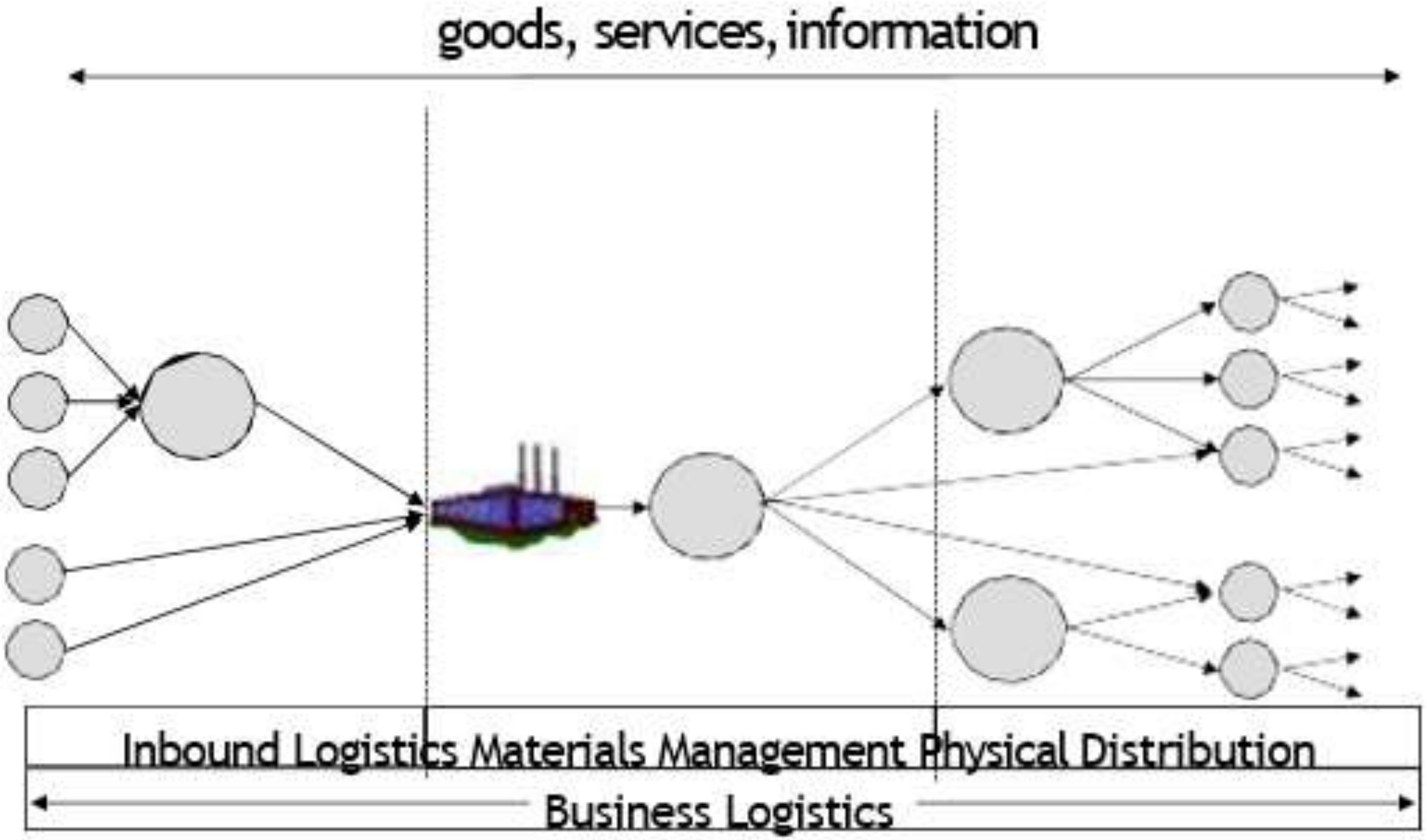
Supply Network Importance

- Efficient supply network is key to bottom line profit of most firms
- Some estimates
  - Worldwide, companies on average spend 12% of GDP on supply network logistics
  - In the United States, a recent estimate is that 10.5% of GDP is spent on supply network logistics
    - $1.12 trillion annually
  - Costs range from 4% to 30% of sales revenue; 20% on average
  - Second only to cost-of-goods sold

What is Logistics?

- Council of Supply Chain Management Professionals (CSCMP) definition
  - "Logistics management is that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements."
- Key Ideas
  - Forward and reverse flow
  - Efficient and effective
  - Plans, implements and controls
  - Part of supply chain management (SCM)
- Our focus
  - Logistics problems faced by production supply chains
  - Logistics problems faced by transportation service providers

...forward and reverse flow...



…efficient, effective…

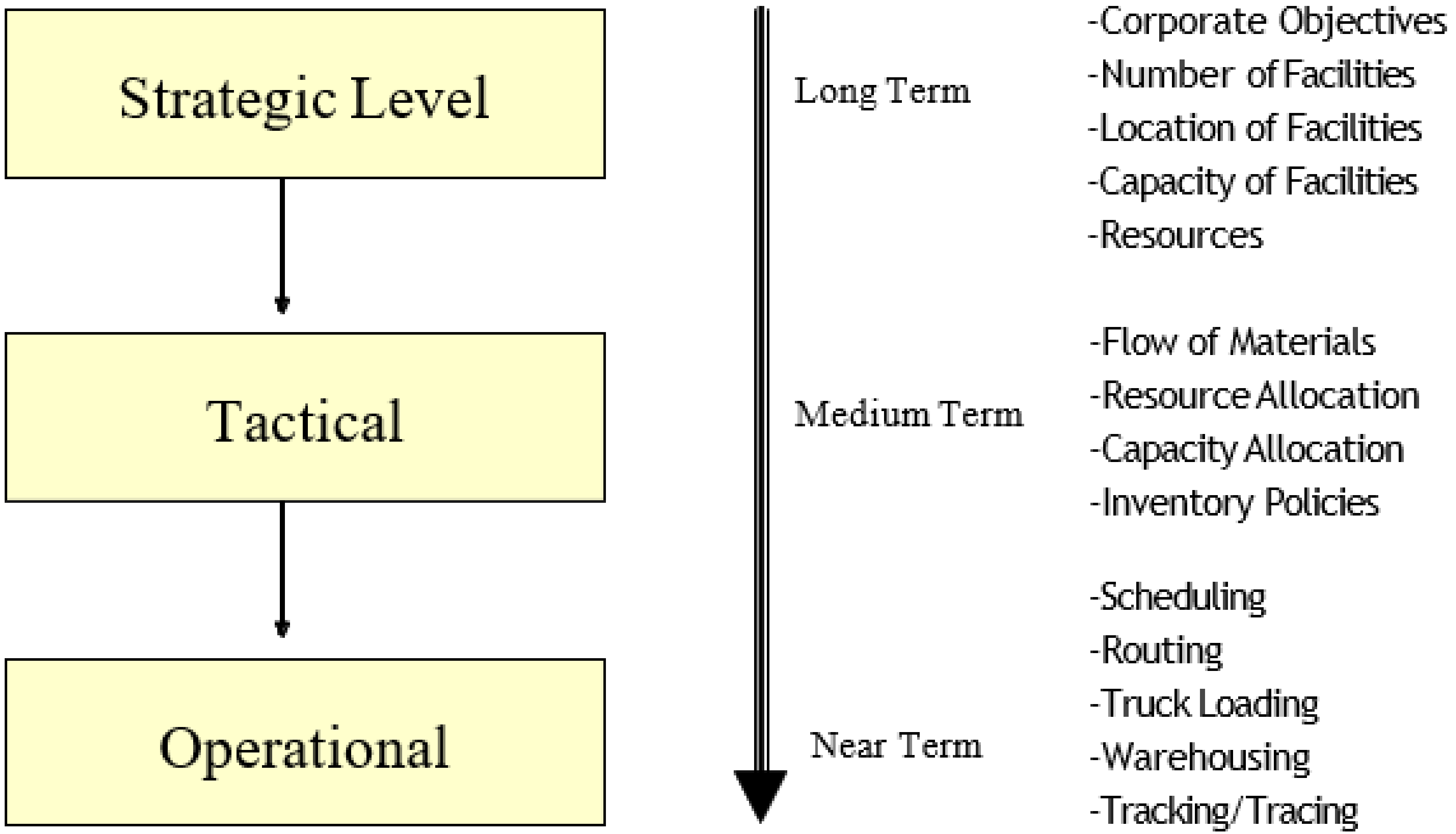
- Effectiveness: delivering on what is committed
  - Price
  - Quality
  - Response time
  - Flexibility

Achieving desired *objective* while minimizing *costs*

- Efficiency: using resources in the “best” way

…plans, implements and controls…

3 levels of decision-making



From Logistics to SCM

- CSCMP definition
  - "Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies."
- Key Ideas
  - Extends concept beyond firm's suppliers and customers
  - Stresses partnerships and collaboration

Supply Chain Management Activities

- All activities required to plan and operate a supply network, including:
  - Relationship management
  - Finance
  - Product marketing
  - Facility design
  - Demand forecasting
  - Inventory control
  - Production planning and scheduling
  - Logistics resource scheduling
  - Transportation management
  - Network design

College of Business

Industrial Facilities Layout and Design, Production Planning and Inventory Control

Challenges in Managing

- Two main challenges
  - Uncertainty
  - Global optimization
- Difficult for one organization
- More difficult for many
- Successful supply chain management can create sustainable competitive advantage
  - Cost
  - Quality
  - Flexibility
  - Response time

Summary

- Logistics
  - Flow of goods, services, and info
  - 3 decision levels
  - Effective, efficient… customer requirements
- Supply Chain Management
  - Includes all organizations in the supply network
  - Stresses collaboration and partnerships
  - All activities required to plan and operate a supply network
- Challenges
  - Uncertainty
  - Global optimality

Truck Overview

Truck Examples: Ranked by 2003 Revenue

- Truckload firms
  - Schneider National (3), J.B. Hunt (7), Swift (8), Werner (12)
- Less-than-truckload firms
  - Roadway (4), Yellow (5), FedEx Freight (6), Con-Way (9), Overnite (10), ABF (13), USF Holland (15)
- Household goods firms
  - United Van Lines (14), North American (24)
- Parcel transporters
  - United Parcel Service (1), FedEx Ground (2)

U.S. Trucking Industry

- Exclusively serves 70% of U.S. communities
- Employees: 9.6 million
- Truck drivers: 3 million
  - Local and Over-the-Road [OTR]
- Fuel: 29 billion gallons diesel per annum
- Miles traveled: 428 billion
  - 116 billion by Class 8 vehicles (18-wheeler trucks)

U.S. Trucking Industry Growth

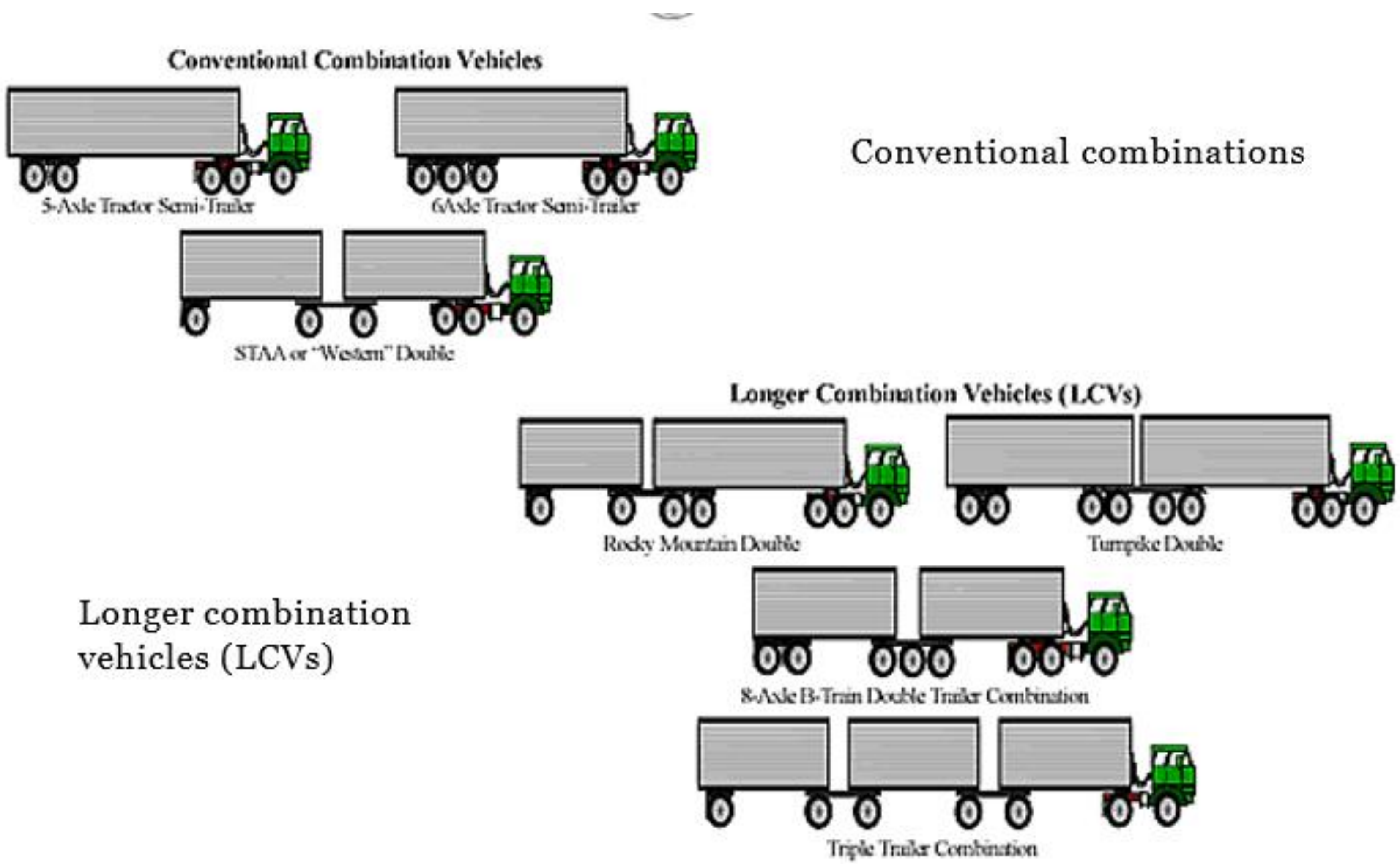
- Increasing in importance
- Freight transport revenue share
  - 68% in 1960
  - 81% in 1997
  - 87% in 2003 (of $610 billion)
- Continuing growth
  - Lean supply chains; just-in-time
  - E-commerce
  - Primary beneficiaries: Parcel, LTL, Air freight

Equipment types in fleets

- Single-unit trucks: 68%
  - Delivery vans, tank trucks, dump trucks, cement mixers
- Tractor-semitrailer combination: 26%
  - Often, “18-wheelers”
  - Lengths (US): 40 to 53 feet
- Multi-trailer combinations: 6%
  - STAA doubles: twin 28’ trailers
  - Longer combination vehicles: Rocky Mt Doubles, Turnpike Doubles, Triples

Vehicle Combinations

Conventional combinations



Longer combination vehicles (LCVs)

Single-unit: delivery vans

Tractor semi-trailer combinations

Multi-trailer combinations

Intermodalism

- Economics
  - Can be slower
  - Origin and destination drayage
  - Huge cost savings in driver pay
- Long-haul trips
  - 500-700 miles
  - Hub-to-hub trips in LTL and package express trucking
- TOFC vs. COFC
  - Equipment investment and management vs. price

TOFC

- Trailer-on-flatcar
- 28’ Highway trailers

Double-stack COFC (1979)

- Container-on-flatcar
- Articulated cars
- Clearances
  - bridge/tunnel investments

Trucking industry trends

- Value-added
  - Tracking and tracing, online quotes and service requests
- Dedicated contract carriage
  - Replacement for private carriage: outsourced
- Time-sensitive transportation
  - Expedited options: FAST
  - Time-definite delivery: RELIABLE
- 3PL Services
  - Warehousing, distribution management, handling

Truckload operations

- Direct origin-to-destination service
  - No equipment changes
  - No intermediate terminals required

- General vs. specialized
  - Refrigerated vans (“reefers”), automobile transports, grain carriers

- Planning issues
  - Supply-demand balancing (backhauls, empty repositioning)
  - Driver issues (relays, home stays)

Truckload operating problem

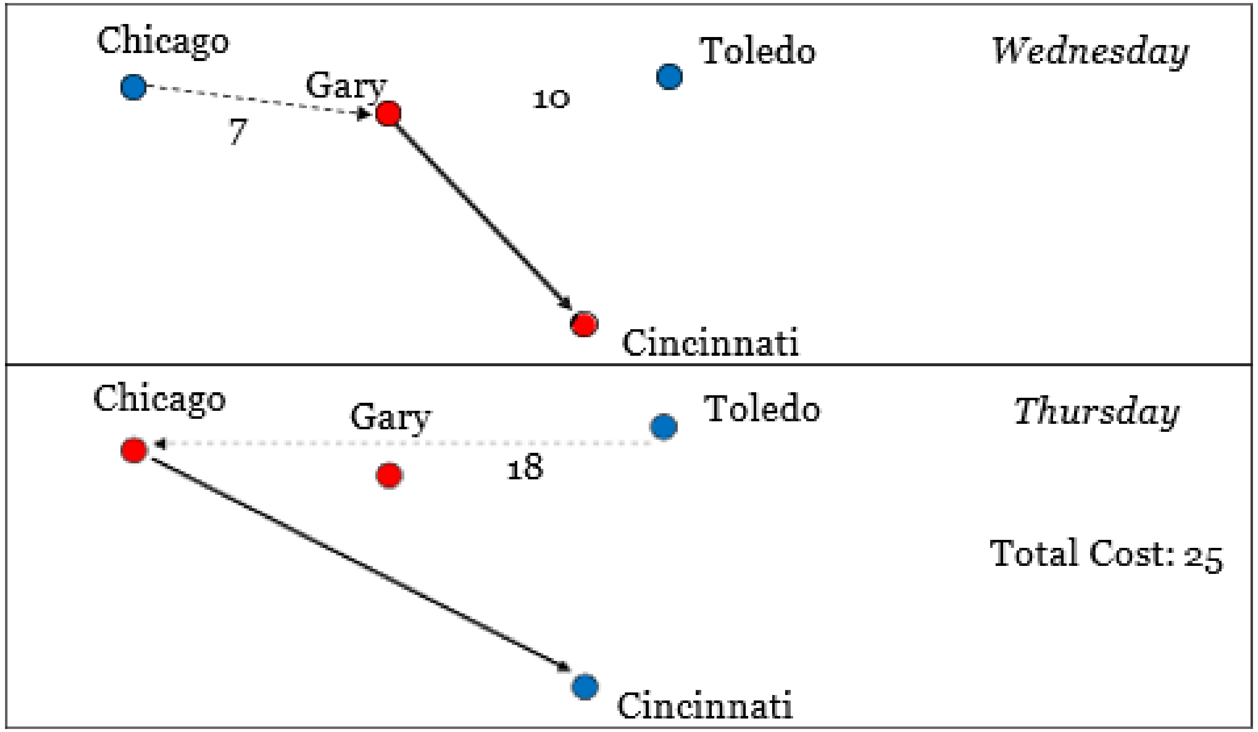
- Given a load request…
  - Origin and destination
  - Pickup time
  - Number of trailers requested

- …decide
  - Driver/trailer combination to assign

- Why difficult?
  - Short-term load visibility
  - Loaded flow imbalance

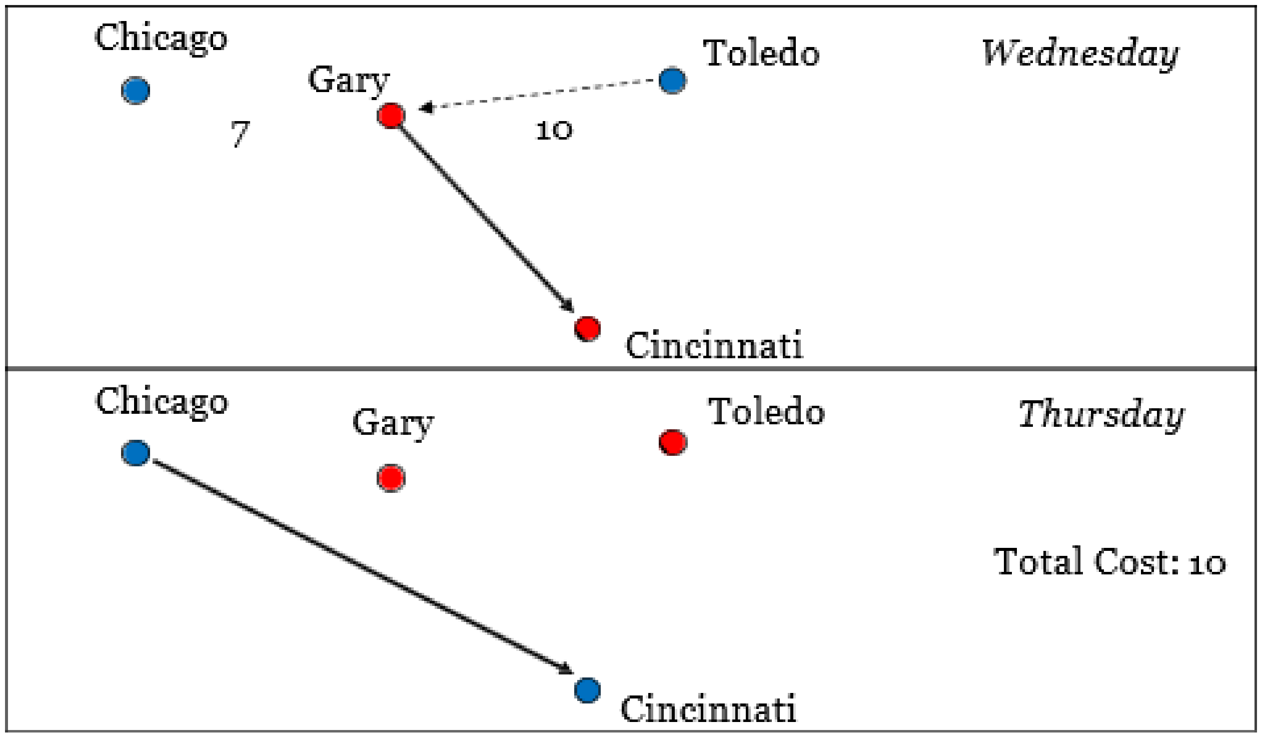
Truckload operating problem

- Short-term load visibility



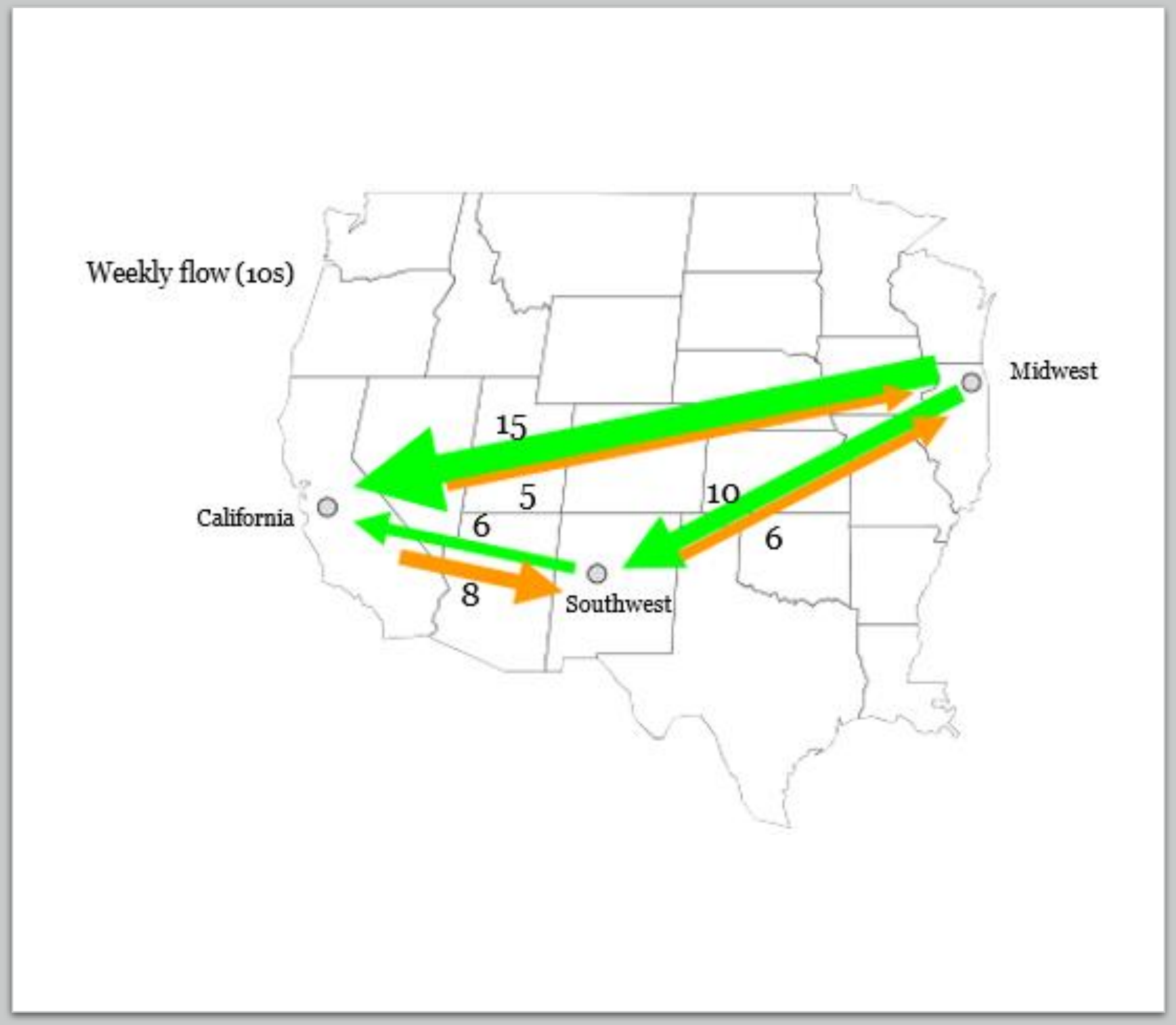
Truckload operating problem

- If you could forecast load from Chicago…



Truckload operating problem

- Geographic flow imbalances

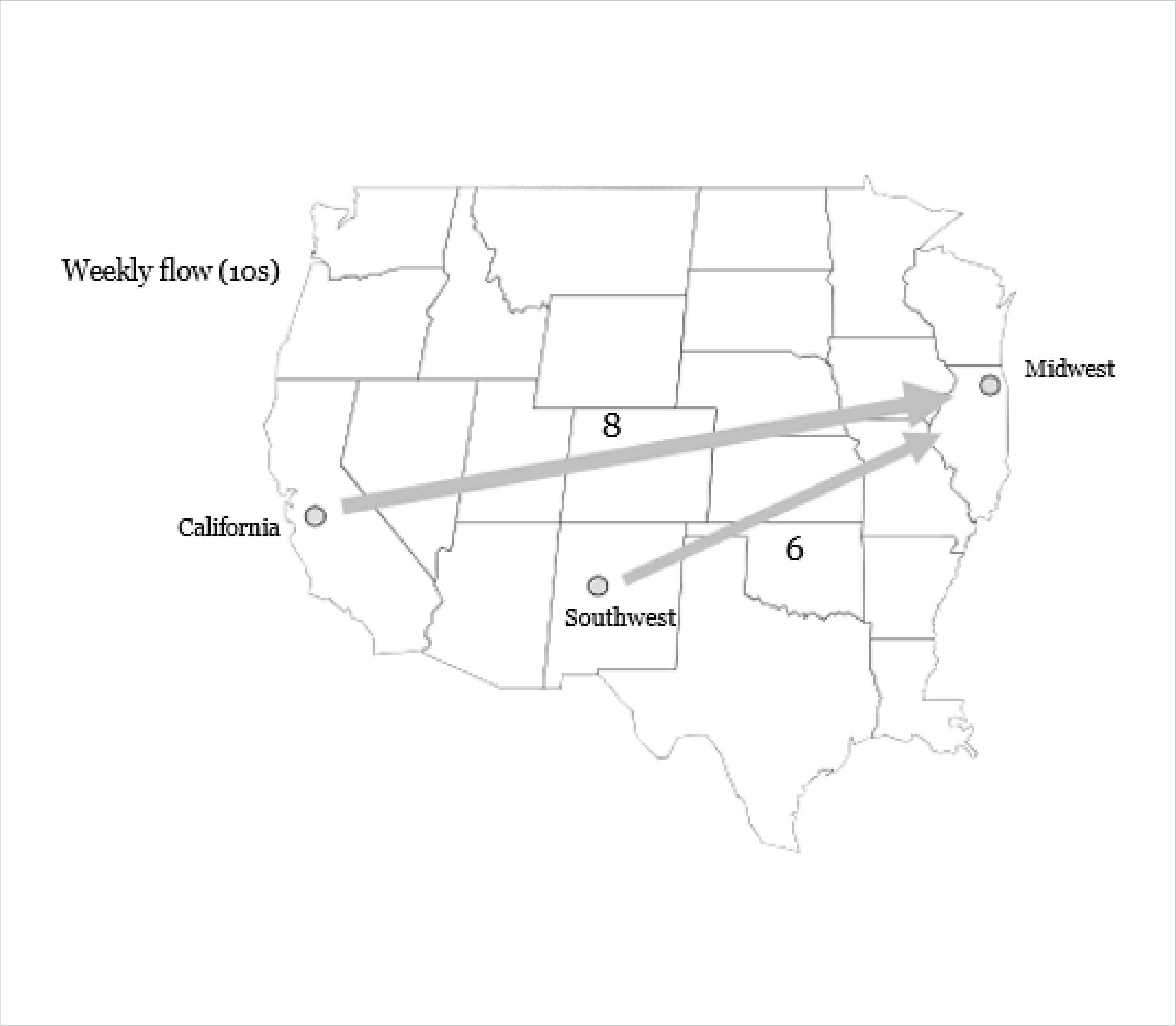


Truckload operating problem

- Geographic flow imbalances

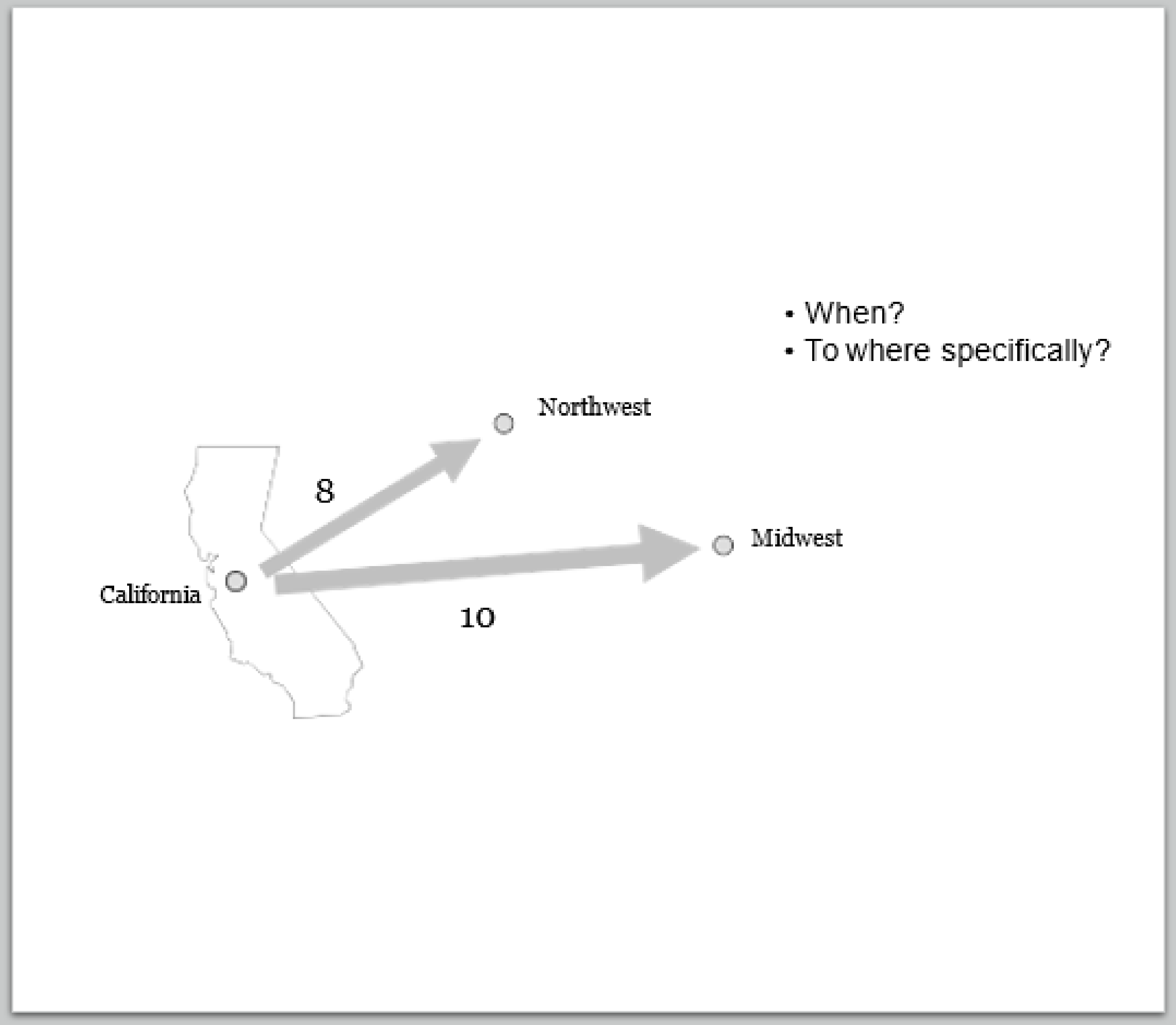
Truckload operating problem

- Empty flow plan



Truckload operating problem

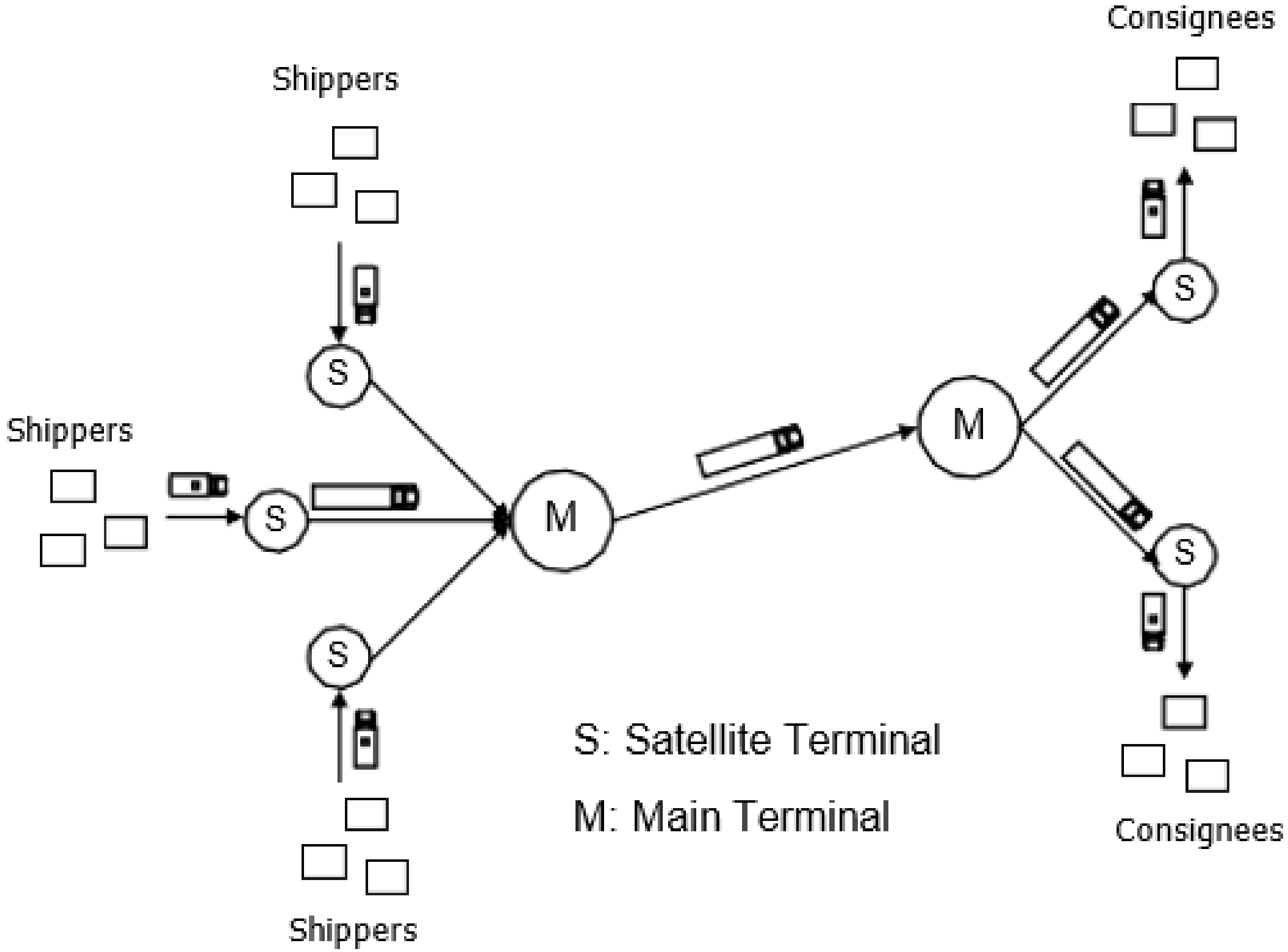
- Empty flow plan challenges
  - Complex networks
  - Flow timing
- Plans devised by aggregating to weekly demands infeasible?
  - Implementation



Less-than-Truckload (LTL) operations

- Small shipments
  - 250 to 12,000 lbs.
  - Cube (volume) is usually constraint on vehicle packing
- Hub-and-spoke networks
  - Consolidation and rerouting role of terminals
- Planning issues
  - Network design
  - Routing and scheduling problems

Less-than-Truckload (LTL) operations



Service network design and operation

- How to consolidate flows of shipments over a network of distribution centers to minimize transportation and handling costs while maintaining level of service
  - *Design* service network, i.e., the pairs of terminals between which direct service is offered
  - *Operate* a load plan, i.e., guidelines for each terminal indicating where shipments headed for destination *d* should be loaded to next
  - Design problem considers both!

Fundamental model: min cost paths

- Given a load must be moved from point A to point B, what is the least "cost" truck route over the road system?
- Trucking uses
  - Path-finding (above)
  - Standard mileage for driver pay
  - Standard mileage for rate negotiation
  - Generation of input to routing and scheduling models

Fundamental model: min cost paths

- What is cost? → application-dependent
- Distance
  - Certain costs, like driver pay, fuel costs, and equipment wear- and-tear may depend directly on distance traveled
- Travel time
  - Customer service considerations often warrant minimum travel time paths
  - “Consumer” uses of min cost paths, e.g. Google Maps, usually use travel time minimization as the objective
- Dollar costs

Transportation Rates and Costs

Rate structures of common carriers

- Related to shipment size
- Related to distance
- Related to demand
- Related to product shipped
- Class rates

Rate structures-Related to shipment size

- Rates depend on shipment size, and most typically size is measured in units of weight or mass. Rates are quoted in $ per cwt (100 lbs). Usually several categories, or “rate breaks”, based on several weight cutoffs.

Rate structures-Related to shipment size

1. For LTL or LCL shipments, minimum total rate for quantities below a minimum threshold, then several weight categories with different rates.

2. For FTL or FCL, rate only depends on equipment size ordered.

3. Incentive rates: for loads utilizing multiple vehicles, or even trainload rates in the case of unit trains (why? because terminal costs are reduced)
4. Time-volume rates: encourage shippers to send minimum quantities regularly, in effort by carriers to ensure regular flow of business. (here "volume" refers to freight throughput, not cube)

Rate structures-Related to distance

1. Uniform rates: rate independent of distance (e.g. USPS Priority Mail. Why? Most of the cost is in handling.)
2. Proportional rates: Fixed rate + variable rate per distance. (no taper, but still includes EOS. why?) Truckload rates often like this.
3. Tapered rates: Increase with distance, but at a decreasing rate. Especially in air transportation.
4. Blanket rates: constant rates for certain intervals of distance, usually to match competitors rates. Grain, coal, and lumber. UPS Rates.

Rate structures-Related to demand

- Often, carriers adjust rates to what shippers are willing/can afford to pay: “what the market will bear.”

Rate structures-Related to product shipped

- Products are grouped into a classification for the purposes of determining rates. Classes depend on the factors of density, stowability, ease of handling, and liability:
- Weight/volume
- Value/weight or value/volume
- Liability to loss, damage, or theft
- Likelihood of injury/damage to other freight, to personnel, to vehicles and equipment
- Risk of hazardous materials
- Security of container or packaging
- Expense of and care in handling
- Rates on analogous articles, competitive products

Cost characteristics by mode

- Fixed costs: right-of-way, vehicles and other equipment, terminals, other overhead.
- Variable costs: fuel, maintenance (oil, tires, service), drivers.

Cost characteristics by mode

Rail

- High fixed costs: infrastructure (railbed, train control systems (signals), switching yards, terminals, locomotives, rolling stock).
- Small variable costs: fuel, crews, efficiency of steel wheels on rail.
- High terminal costs: load/unload, transshipment, yard-switching to assemble/disassemble trains.

Motor Truck

- Lowest fixed costs: trucks, trailers, and terminals.
- High variable costs: drivers, fuel, oil, tires, maintenance. Fuel costs include fuel taxes. Lower terminal costs than rail.

Cost characteristics by mode

Water

- Medium-high fixed costs: expensive vehicles and terminals, no right-of-way infrastructure.
- Variable costs low: low speed, high capacity vehicles.
- Terminal costs lower than rail, higher than motor trucks; harbor fees and loading/unloading costs.

Air

- High fixed costs: very-expensive vehicles, terminal facilities.
- Variable costs medium-high: high fuel costs, relatively low-capacity vehicles: decrease with distance due to take-off and landing fuel inefficiencies, labor, maintenance.
- Terminal costs: High, airport landing fees, storage, space leasing, load/unload costs.

Cost Classification

It is useful to classify costs into four essential types:

1. Transportation costs: movement via vehicle, loading/unloading
2. Handling costs: packing/unpacking “containers” (boxes, bags, pallets), intra-facility movements such as moving into and out of storage
3. Holding costs: opportunity cost of capital for time waiting
4. Facility rent costs: economic “rent” for facility space, storage infrastructure and maintenance

Mode Choice Problem

Given the cost profiles of different modes for a particular shipment, which option is most economical?

- Normalize all costs to common unit and time
- Compare total cost of each mode

Minimum-cost path models

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Transportation decision modeling

- Frequently, decision-support systems for transportation require methods for finding a minimum-cost path between points. Points could be geographic locations, or more abstractly represent any type of point in time and/or space.

"Costs" could be:

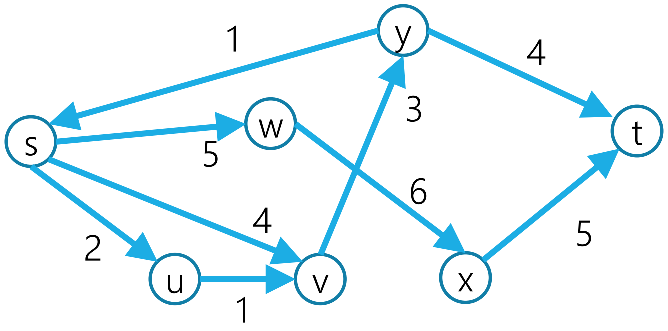
- Distances
- Times
- More general costs, represented in $

Shortest Paths

The **length** of a path is the sum of the edge weights on that path.

Given: a directed graph G and vertices s and t

Find: the shortest path from s to t



Minimum-cost path models

Shortest-path calculations are based on a network model: a network or graph *G* includes a set of points called nodes N, and a set of arcs connecting the points *A*: $G = (N, A)$. Arcs are often referenced as (i,j); connecting node *i* to node *j*. Arcs may have a number of characteristics, but for shortest paths must include a cost characteristic: the cost c_{ij} of arc (i,j) is the cost for travel from *i* to *j*.

Minimum-cost path models

It's important to recognize the decision structure of a network model. Each node i represents a "point" at which a decision is made, and each arc (i, j) represents a decision that moves us from decision point i to j.

Transportation application: Given a network model representing the transportation system (roadways, railways, air traffic lanes) for a given mode, determine the minimum time (distance, cost) path from an origin point to a destination point.

Dijkstra's algorithm

- Requires that $c_{ij} \geq 0$

Initialization:

$$v(j) \leftarrow \begin{cases} 0 & j = s \\ +\infty & \text{otherwise} \end{cases}$$

$$pred(j) \leftarrow \begin{cases} 0 & j = s \\ -1 & \text{otherwise} \end{cases}$$

$PERM = ; \overline{PERM} = N$

Iterations:

while $\overline{PERM} \neq \emptyset$:

1. Let $p \in \overline{PERM}$ be node for which $v(p) = \min\{v(j), j \in \overline{PERM}\}$
2. $PERM \leftarrow PERM \cup \{p\}$
3. $\overline{PERM} \leftarrow \overline{PERM} \setminus \{p\}$
4. For every arc $(p, j) \in A$, $j \in \overline{PERM}$ leading from node p:
   (a) if $v(p) + c_{pj} < v(j)$, then:
      - $v(j) \leftarrow v(p) + c_{pj}$
      - $pred(j) \leftarrow p$

Dijkstra’s algorithm

1. Assign to every node a distance value. Set it to zero for our initial node and to infinity for all other nodes.
2. Mark all nodes as unvisited. Set initial node as current.
3. For current node, consider all its unvisited neighbors and calculate their tentative distance (from the initial node). For example, if current node (A) has distance of 6, and an edge connecting it with another node (B) is 2, the distance to B through A will be 6+2=8. If this distance is less than the previously recorded distance (infinity in the beginning, zero for the initial node), overwrite the distance.

Dijkstra's algorithm

4. When we are done considering all neighbors of the current node, mark it as visited. A visited node will not be checked ever again; its distance recorded now is final and minimal.

5. If all nodes have been visited, finish. Otherwise, set the unvisited node with the smallest distance (from the initial node) as the next "current node" and continue from step 3.

Dijkstra's algorithm

- Pros
  1. Achieves fastest running times (theoretically and practically) for dense networks. Typical geographic networks are not dense, though.
  2. Can be truncated. Each iteration, one node p is given a permanent, optimal minimum cost label and predecessor. Thus, if you are interested only in paths to some subset of the nodes $T \subset N$, you can stop the algorithm once $PERM \supseteq T$.
- Cons
  1. Alternative methods are faster (practically) on sparse networks.
  2. Efficient implementations require programming a priority queue (heap).

Bellman-Ford algorithm

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Bellman-Ford algorithm

- Sometimes, label-correcting algorithm. No requirement of non-negative arc costs. Often more efficient in practice for sparse transportation problems.

Bellman-Ford algorithm

Bellman-Ford algorithm

Sometimes, *label-correcting* algorithm. No requirement of non-negative arc costs. Often more efficient in practice for sparse transportation problems.

Initialization:

$$v(j) \leftarrow \begin{cases} 0 & j = s \\ +\infty & \text{otherwise} \end{cases}$$

$$pred(j) \leftarrow \begin{cases} 0 & j = s \\ -1 & \text{otherwise} \end{cases}$$

$LIST = \{s\}$

Iterations:

while $LIST \neq \emptyset$:

1. Remove node p from top of $LIST$
2. For every arc (p, j) leading from node p:

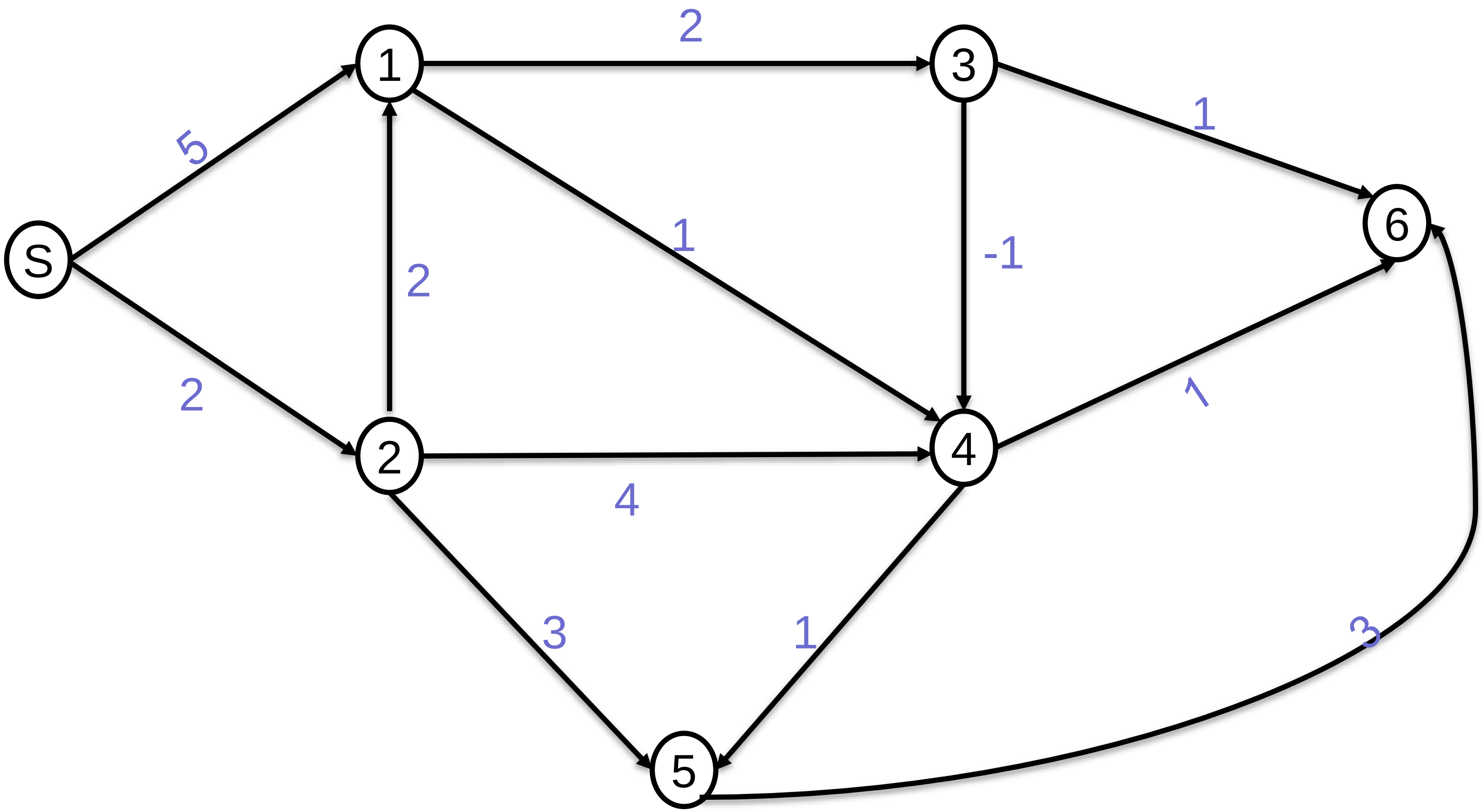
   (a) if $v(p) + c_{pj} < v(j)$, then:

   - $v(j) \leftarrow v(p) + c_{pj}$
   - $pred(j) \leftarrow p$
   - if $j \notin LIST$, $LIST \leftarrow LIST + \{j\}$

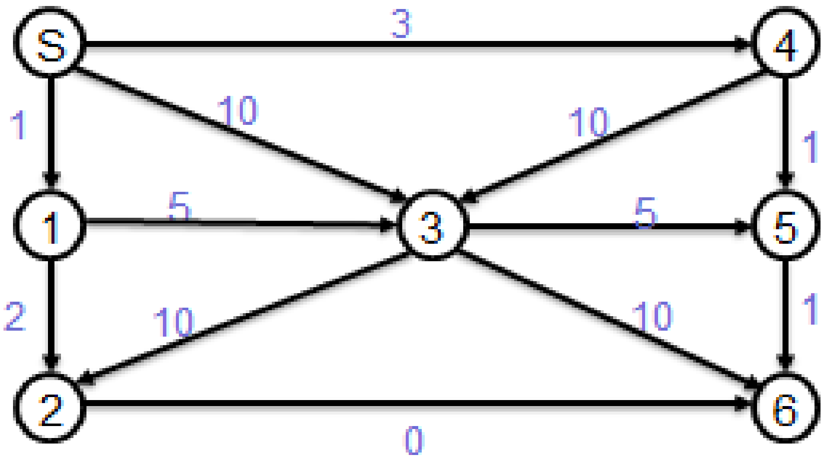
Bellman-Ford algorithm

- Pros
  1. Achieves fastest running times (practically) for sparse networks, especially when implemented with Pape's Modification.
  2. Very simple to implement.
- Cons
  1. Labels and predecessors not optimal until full completion of algorithm.
  2. Running time may be slow on dense networks due to frequent label updates.

- Example



Question 1: Given the graph in the Figure shown below, find the shortest paths to all nodes using the vertex S as the starting source. Use Dijkstra's algorithm and Bellman algorithm.

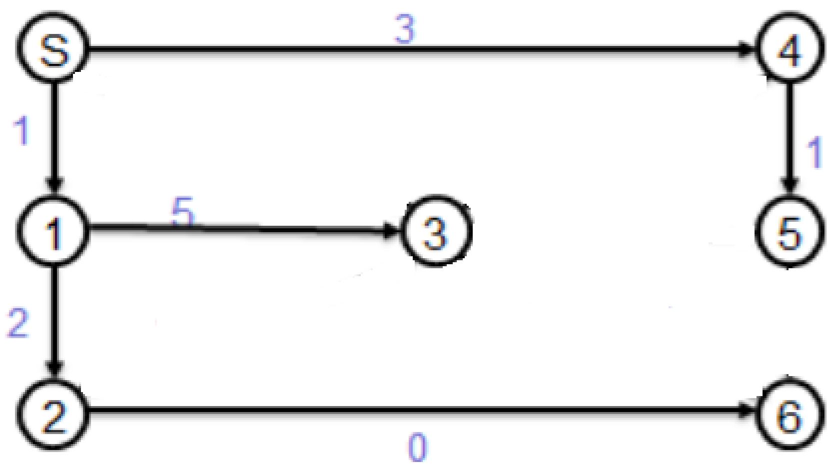


Iteration	S	1	2	3	4	5	6	P	PERM	$\overline{PERM}$
0										
1										
2										
3										
4										
5										
6										
7										

Iteration	s	1	2	3	4	5	6	P	LIST
0									
1									
2									
3									
4									
5									
6									
7									
8									

Solution:

Minimum cost path tree



Solved Example

Choosing a Transportation Mode

A computer manufacturer ships partially assembled computers (hereafter called units) from an assembly plant in Thailand to a distribution center in Oregon. We want to determine if it is more economical to ship in 40ft containers by ocean carriers or in airline containers by air carriers. Shipment by ocean costs $11,000 per container, and a 40ft container can hold 5,000 units. Handling cost is $2000 per 40ft container. The journey by sea takes 20 days on average. Shipment by air costs $20,000 per container, and an airline container can hold 1,400 units. Handling cost is $1000 per airline container. The journey by air takes 2 days on average (door to door). The forecasted demand is 120,000 units for the next year, which is also the planned production quantity. No safety stock is kept at the assembly plant, and a shipment is sent to the distribution center as soon as a container is filled. Safety stock of 1,000 units is kept at the distribution center. A unit is valued at $600 at the assembly plant and $800 at the distribution center. The inventory holding cost rate is estimated at 20% of value per year. The space cost is estimated as $30 / unit*year at the assembly plant and $40 / unit*year at the distribution center.

1. What are the annual inventory holding costs at the assembly plant? (Include the space and holding cost in this calculation.)
   Annual inventory holding costs at the assembly plant =$90q/year

2. What are the annual inventory holding costs at the distribution center? (Include the space and holding cost in this calculation.)
   Annual inventory holding costs at the distribution center =(120q +200,000)$/year

3. What are the pipeline inventory costs for each mode?
   Pipeline inventory holding cost by ocean =$920,547.95/year
   Pipeline inventory holding cost by air =$92,054.795/year

4. What are the transportation costs for each mode? (Don't forget to take the shipment handling cost into consideration when calculating these costs.)
   Transportation cost for Ocean= (1,560, 000,000/q) 0<=q<5,000
   Transportation cost for air= (2,520,000,000/q) , 0<=q<1,400

5. What are the total cost equations for each mode of transportation?

   TC ocean= $210q/year+$1,120,547.95/year+(1,560, 000,000/q)
   TC air= $210q/year+$292,054.795/year+ (2,520,000,000/q)

6. Assume that the shipper will always ship full loads. Determine the most economical transportation service to use in this case.

   TC ocean (full container, q=5000)=$2,482,547.95/year
   TC air (full container, q=1400)=$ 2,386,054.795/year

   So for Full container load, shipment by air is better since it has lowest total annual

7. Now assume that the shipper may use less than full loads. Determine the most economical transportation service to use in this case. (This means that you want to find the optimal shipment size for each mode, but remember to take the container restrictions into consideration.)

To find optimal shipment quantity (q*) take the first derivative and make it equal to zero (calculus)
dTC/dq= -A/q2+B=0
for ocean: -1,560,000,000/q2+210=0
for air: -2,520,000,000/q2+210=0

q* (ocean)= =2726, since (q*=2726 unit << 5,000 unit) container capacity
q* (air) =3465>>1,400 units, so the actual q* is full container **q*=1400 unit**

Now plug the values of q* in the TC (q*) equations:
TC (q*) ocean=1,560,000,000/ q* + 210 q* + 1,120,547.95
TC (q*) ocean=1,560,000,000/ 2726 + 210 *(2726) + 1,120,547.95**=$2,265,275.0079**

TC (q*) air=2,520,000,000/ q* + 210 q* + 292,054.79
TC (q*) air=2,520,000,000/ 1400 + 210 *(1400) + 292,054.79= **2386054.79**

So for less than container load, shipment by ocean is better since it has lowest total annual