Lecture 08: Network Design and Site Selection

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Outline

Key Ref.: [JC10] [Bal07] [CM07] [Goe11]

Why do we transportation?

- **Economics:** scales, low cost, JIT
- **Geographic** raw material, markets, resources (labor)
- **Proprietary:** special process, softwares, R&D
- **Environment:** danger, hazard

Trade-Off in transportation design

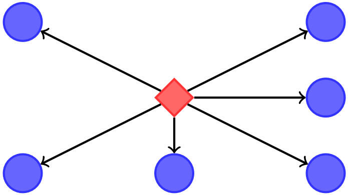
- Inventory Cost **VS** Transportation Cost
- Responsive **VS** Transportation Cost

What should you know about network?

- **Goal:** minimizing costs, min-max service levels, min-max hazard/risk
- **Echelon Level:** warehouse–DC, retailer–customer
- **Infrastructure:** transit facility, inventory, trucks, equipments, WMS
- **Routing:** dynamic **VS** static
- **Visiting Policy:** single destination **VS** milk-run

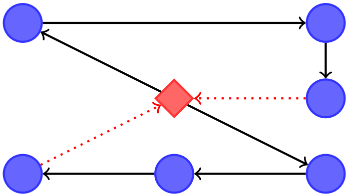
Distribution network: steps taken to move and store products from suppliers to targeted customers in a supply chain

Single Destination



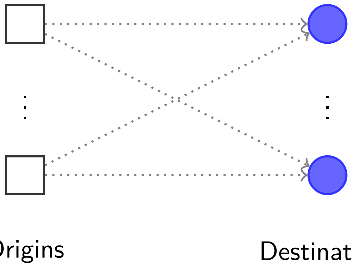
- **Idea:** visiting single location in each trip
- **Pros:** simple, high-level model
- **Cons:** fleet management, # trucks
- **Examples:** *rarely seen in pure form* why?

Milk Run Network



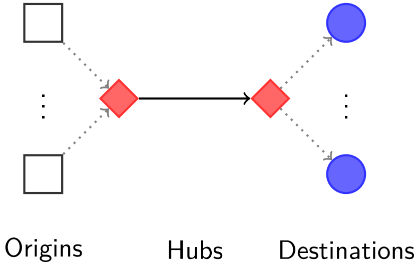
- **Idea:** visiting many locations in one trip
- **Pros:** high utilization, low inventory
- **Cons:** high shipment frequency, required planning/routing
- **Examples:** 7-Eleven (DC to stores)

Direct Shipment Network



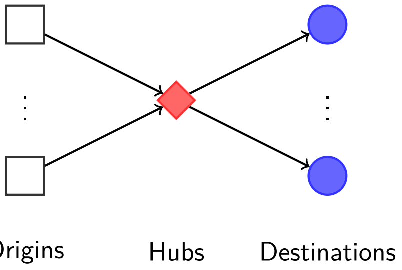
- **Pros:** simplest network, low transit time, required no facility or IT
- **Cons:** more vehicles, no consolidation, low utilization
- **Examples:** urgent delivery, full truckload shipment

Hub-and-Spoke Network



- **Idea:** hub as a temporary destination/origin to consolidate
- **Pros:** economies of scale → high utilization
- **Cons:** required facilities and sorting machine, higher transit time
- **Examples:** Airlines, Mails, 3PL Companies

Single-Hub Network: Crossdocking



- **Idea:** variation of hub-and-spoke for relatively high flow
- **Pros:** low transit time, economy of scale, high utilization
- **Cons:** required facilities and sorting
- **Examples:** Crossdocking (Wal-Mart, Home depot), large 3PL Companies

Why do we need a model?

- understand and analyze network
- predict and determine decisions

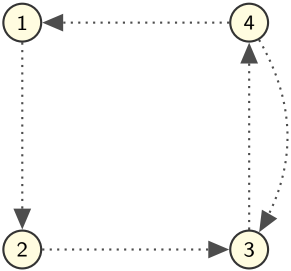
Quantitative Model Components

- **Assumptions:** simplify factors, capture important parts
- **Data:** verify parameters and distributions
- **Model:** describe key relationships and interactions
- **Tools:** spreadsheet, optimization, simulation
- **Conclusion:** suggestions and insights, not numerical value

Network optimization model: graph theory based model

- Shortest Path Problem; Transportation Problem
- Capacitated Plant Location Problem
- Traveling Salesman Problem (TSP)

Introduction to Graph Theory



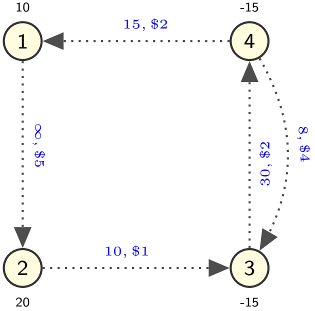
- **Node:** (vertex) presentation of stage

$$\mathcal{N} \in \{1, 2, 3, 4\}$$

- **Edge:** (arc) connecting line between nodes

$$\mathcal{E} \in \{(1,2), (2,3), (3,4), (4,1), (4,3)\}$$

Parameters in Graph



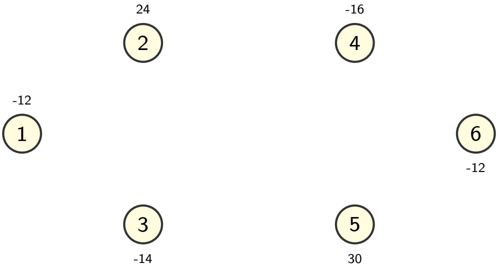
- **Demand/Suppy:** demands and supply at each node, e.g. demands at node 1 is 10
- **Cost:** incurred cost per a unit of flow, e.g., cost at edge $(1, 2)$ is 5
- **Capacity:** unit flow allow at each edge, e.g., flow at edge $(1, 2)$ must be less than ∞

Simple Network

A network with 6 vertices, $\mathcal{N} \in \{1,2,3,4,5,6\}$, and $\{-12,24,-14,-16,30,-12\}$ demands/suppies at vertices and the following cost and capacity at each edge. Construct the graph of this network

Edge	Cost	Max Capacitiy
(1,2)	$2	6
(2,4)	$2	6
(4,6)	$2	6
(5,6)	$2	6
(3,5)	$2	6
(1,3)	$2	6
(1,5)	$5	∞
(2,3)	$1	2
(2,6)	$5	∞
(4,5)	$1	2

Graph Representation

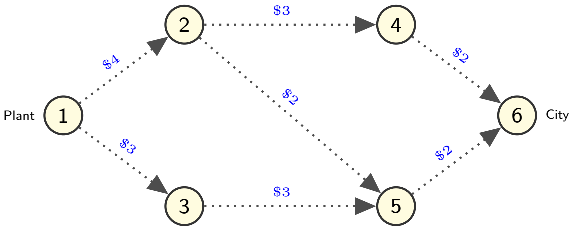


Shortest Path

- **What:** model describes the shortest/fastest path to transport product(s) from origin to destination
- **Idea:** minimizing total times/distances
- **Assumption:** single product, no capacity
- **Components:**
  - single origin/ single destination
  - transit nodes
- **Application:** GPS

Shortest Path

[Winston 2003. Example 8.1] Based on the following network, find the shortest way to transport products from Plant to City.



- **optimal:** $8
- **path 1:** $1 \to 2 \to 5 \to 6$
- **path 2:** $1 \to 3 \to 5 \to 6$

Shortest Path

$$\min \; z = 4x_{1,2} + 3x_{1,3} + 3x_{2,4} + 2x_{2,5} + 3x_{3,5} + 2x_{4,6} + 2x_{5,6}$$

$$\begin{aligned}
\text{Node 1;} \quad & -x_{1,2} - x_{1,3} &&= -1 \\
\text{Node 2;} \quad & x_{1,2} - x_{2,4} - x_{2,5} &&= 0 \\
\text{Node 3;} \quad & x_{1,3} + x_{3,5} &&= 0 \\
\text{Node 4;} \quad & x_{2,4} - x_{4,6} &&= 0 \\
\text{Node 5;} \quad & x_{2,5} + x_{3,5} - x_{5,6} &&= 0 \\
\text{Node 6;} \quad & x_{4,6} + x_{5,6} &&= 1 \\
\text{Non Neg;} \quad & x_{i,j} &&\geq 0 \qquad \forall\, (i,j) \in \mathcal{E}
\end{aligned}$$

Observations

- supply $=$ demand; $\sum$ RHS $= 0$
- each DV appears twice in model

Transportation Problem

- **What:** model describes the cheapest way to allocate products
- **Idea:** minimizing total costs while satisfying all demands and supplies
- **Assumption:** single product, assignment (no routing nor capacity)
- **Components:**
  - two groups of facilities/agents
  - limited supplies and demands
  - limited transportation capacity
- **Application:** Parcel shipment
- **Other Names** Demand Allocation

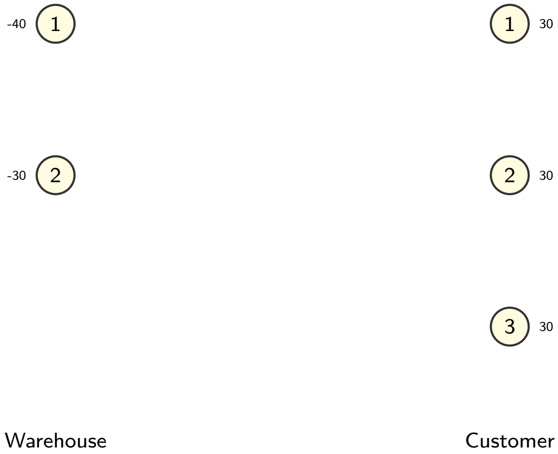
Transportation Problem

[Winston 2003. Question 7.1.1] A company supplies goods to three customers. Each of which requires the goods up to 30 units. The company has two warehouses. Warehouse 1 has 40 units available and warehouse 2 has 30 unit available the cost of shipping one unit from warehouse to customer are listed as follows:

	To		
From	Customer 1	Customer 2	Customer 3
Warehouse 1	$15	$35	$25
Warehouse 2	$10	$50	$40

Construct the graph representative of this network and find the optimal allocation

Transportation Problem: Graph



Transportation Problem: Model

$$\min\ z = 15x_{w1,c1} + 35x_{w1,c2} + 25x_{w1,c3} + 10x_{w2,c1} + 50x_{w2,c3} + 40x_{w2,c3}$$

$$\begin{aligned}
&\text{s.t.} \\
\text{node w1;}\quad & -x_{w1,c1} - x_{w1,c2} - x_{w1,c3} = -40 \\
\text{node w2;}\quad & -x_{w2,c1} - x_{w2,c2} - x_{w2,c3} = -30 \\
\text{node 0;}\quad & -x_{0,c1} - x_{0,c2} - x_{0,c3} = -20 \\
\text{node c1;}\quad & x_{w1,c1} + x_{w2,c1} + x_{0,c1} = 30 \\
\text{node c2;}\quad & x_{w1,c2} + x_{w2,c2} + x_{0,c2} = 30 \\
\text{node c3;}\quad & x_{w1,c3} + x_{w2,c3} + x_{0,c3} = 30 \\
\text{non-neg.;}\quad & x_{i,j} \geq 0 \qquad \forall\ (i,j) \in \mathcal{E}
\end{aligned}$$

Capacitated Plant Location

- **What:** model describes the cheapest way to setup facilities and their allocations
- **Idea:** minimizing total costs while satisfying all demands and supplies/ capacities
- **Assumption:** single product, assignment (no routing)
- **Components:**
  - set of possible location
  - limited supplies and demands
  - limited transportation capacity
  - unable to supply, unless facility is built
- **Application:** Preliminary network design, Parcel-based network

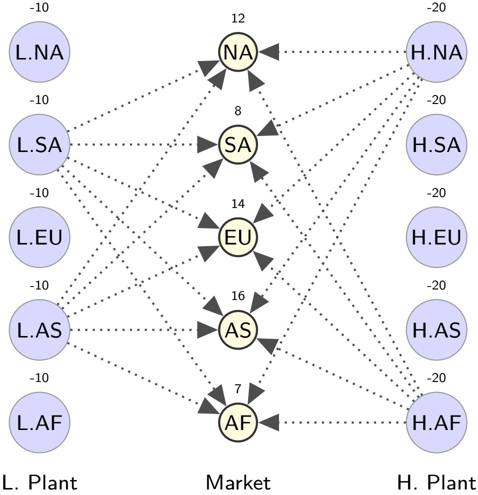
Example of CPL Problem

[*Chopra & Meindl 2010.*] SunOil, a manufacturer of petrochemical production, wants to set up facilities to supply demand in each region. The facility, production, transportation costs are listed as follows:

	prod. & trans. costs					low cap.		high cap.	
Region	N. Amer	S. Amer	Europe	Asia	Africa	fixed	cap	fixed	cap
N. Amer	81	92	101	130	115	6,000	10	9,000	20
S. Amer	117	77	108	98	100	4,500	10	6,750	20
Europe	102	105	95	119	111	6,500	10	9,750	20
Asia	115	125	90	59	74	4,100	10	6,150	20
Africa	142	100	103	105	71	4,000	10	6,000	20
Demand	12	8	14	16	7				

Find the optimal facility location of SunOil.

Graph of CPL Problem



Notation of CPL Problem

Notation & Decision variables

$$
\begin{aligned}
\mathcal{I} &= \text{set of potential plants (capability} \times \text{location)} \\
\mathcal{J} &= \text{set of markets} \\
D_j &= \text{demands at market } j \\
K_i &= \text{capacities of plant } i \\
f_i &= \text{construction costs of plant } i \\
c_{ij} &= \text{cost of prod. and transp from plant } i \text{ to market } j \\
y_i &= \text{plant construction binary decision variable} \\
& \quad y_i = \begin{cases} 1 & \text{if plant } i \text{ is constructed} \\ 0 & \text{otherwise} \end{cases} \\
x_{ij} &= \text{production transported between plant } i \text{ and market } j
\end{aligned}
$$

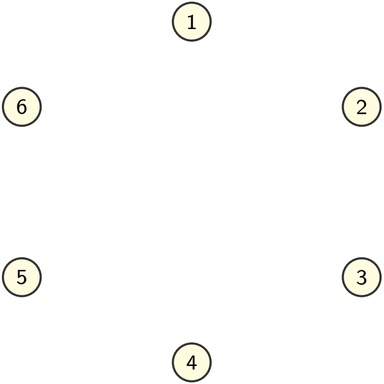
Model of CPL Problem

$$\min \; z = \sum_{i \in \mathcal{I}} f_i y_i + \sum_{i \in \mathcal{I}} \sum_{j \in \mathcal{J}} c_{ij} x_{ij}$$

s.t.,

$$
\begin{aligned}
\text{Supply } i; \quad & \sum_{j \in \mathcal{J}} x_{i,j} && \leq K_i y_i && \forall\ i \in \mathcal{I} \\
\text{Demand } j; \quad & \sum_{i \in \mathcal{I}} x_{i,j} && = D_j && \forall\ i \in \mathcal{I} \\
\text{Non-Neg}; \quad & x_{i,j} && \geq 0 && \forall\ (i,j) \in \mathcal{I} \times \mathcal{J} \\
\text{Binary}; \quad & y_i && \in \{0,1\} && \forall\ i \in \mathcal{I}
\end{aligned}
$$

Intro to TSP



- **Idea:** Given locations, find the shortest distances that all locations once
- **Important:** well-studied because fundamental of routing

Natural Formulation [**IE**]

$$\mathcal{N} = \text{set of locations}$$
$$\mathcal{E} = \text{set of connected locations (edges)}$$
$$c_{i,j} = \text{distances from location } i \text{ to location } j$$
$$x_{i,j} = \text{binary decision variable}$$

$$x_{i,j} = \begin{cases} 1 & \text{if edge } (i,j) \text{ is used} \\ 0 & \text{otherwise} \end{cases}$$

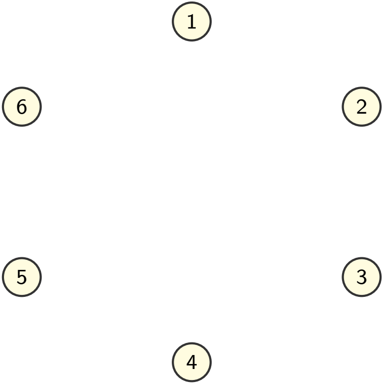
$$\min \ z = \sum_{(i,j) \in \mathcal{E}} c_{i,j} x_{i,j}$$

s.t.

$$\text{node n;} \quad \sum_{i \in \mathcal{N}} x_{i,n} + \sum_{j \in \mathcal{N}} x_{n,j} = 2 \qquad \forall \ n \in \mathcal{N}$$

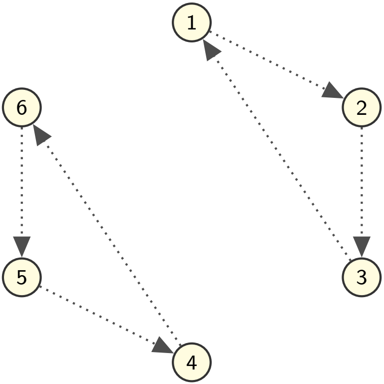
$$\text{non-neg.;} \quad x_{i,j} \in \{0,1\} \qquad \forall \ (i,j) \in \mathcal{E}$$

Example of TSP



- **What:** A 'difficult' ($\mathcal{NP}$-hard) combinatorial problem
- **Why:** number of sub-tour (2^{n-2})
- **How to solve:** taboo search, ant colony

Sub-Tour Elimination [**IE**]



- **add more constraint** $x_{1,2} + x_{2,3} + x_{3,1} \leq 2$

Practical Solution

Observation

- easy to find any TSP solution
- difficult to find optimal solution $\exists\ \frac{(n-1)!}{2}$ possible solution
- topological condition, particularly triangle inequality reduce search space

2-Opt Heuristic

- find any TSP solution (e.g., greedy algorithm)
- remove two edges from the solution
- re-connect TSP with 'new' edges

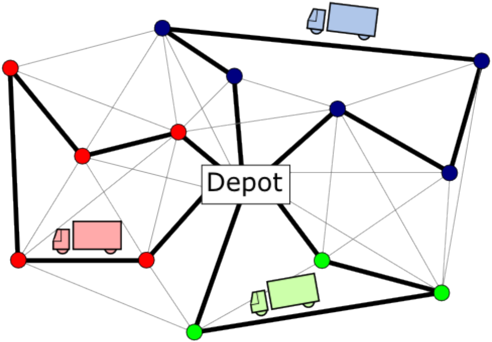
Background of VMI

- **What is Vendor Managed Inventory (VMI)?**
  - Supplier orders/controls inventory for retailers
  - A popular continuous replenishment in retailer business
  - Inventory is managed by vendor, not retailer
- **Implementation**
  - Strong relationships
  - Information Technology → Coordination
  - "Everyday" products
- **Benefits**
  - **Both**: Achieving quick response and more trust
  - **Retailer**: Reducing labors and inventory (space and capital)
  - **Supplier**: Gaining competitive edge and LTL shipments
- **Example**
  - Procter & Gamble and WalMart, HP , Johnson & Johnson

What are operation issues behind VMI?

- **VMI at face value**
  - More information → real time delivery
  - Seamless products transfer → eliminate receiving and inspecting
- **How to improve response time and reduce inventory?**
  - Increasing frequency of shipping
  - Reducing shipping quantities
  - Shipping to multiple retailers
- **Operation issue**
  - VMI → Vehicle Routing Problem (VRP)

Vehicle Routing Problem [++ISE++]



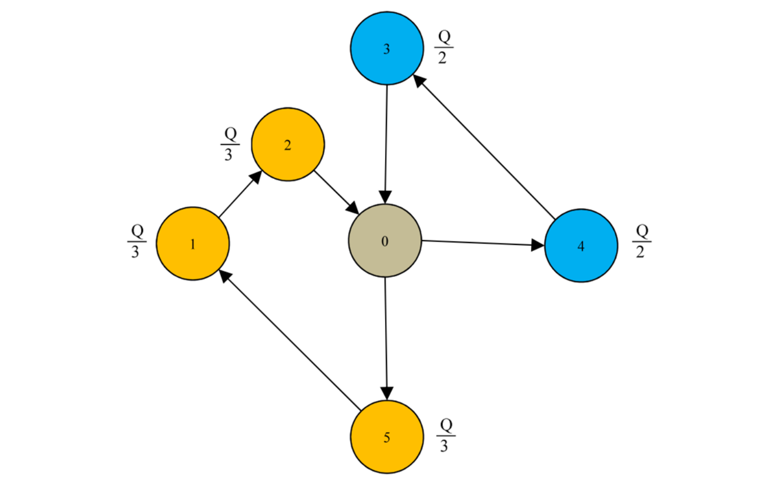
- **What:** model describe routing of vehicle (from/to depot)
- **Idea:** minimizing total times/distances of multiple vehicles

Background of VRP [**IE**]

- **Classification of Routing Problem**
  - **Infinite capacity**: Traveling Salesman Problem (TSP)
  - **Finite capacity**: TSP + Bin Packing Problem (BPP)
  - **Time windows**: specific pick-up and drop-off times in each node
    TSP + BPP + Scheduling Problem
  - **Stochastic**: demands or time windows occurred with some probability

- **Solution Method**
  - **Exact solution:** Mixed Integer Programming
  - **Heuristic:** Traditional (e.g., 2-Opt, greedy) and Meta-Heuristic
  - **Approximated algorithm:**: Heuristic with known error/upperbound

Simple Coordination with VMI/VRP



Cluster of retailer based on inventory

VMI Potential Problems

- **Pilot VMI:** SKUs, vendor selection, hi-involvement
- **Story behind data:** truckload, special order, demand pattern
- **Efficient communication:** new product, seasonal variability
- **Change management:** promotion, compensation

VMI Success Factors

- Focus your efforts → competency & accuracy
- Trust between vendor/retailer → willingness & patience
- Effective computer systems → communication

Importance of Sites and Key Questions

There are three things that matter in property: location, location, location.

- Providing structure to the network
- Affecting inventory and transportation costs
- Improving customer services

Key Questions

- How many facilities should there be? Service VS Scale
- Where should they be located? → copy, compute, wait-and-see
- What size/cap should they be? → usage + expansion + buffer

Nature of Location Analysis

- **Type of Facility**: cheaper to produce/order in large batches; setup cost and time. (man, activities, surroundings)
  - *Plant:* driven by economics
  - *Retail:* driven by revenue.
  - *Service:* driven by service factors.
- **Cost Structure:** investments (tech/cap)+ periodic upkeep (time/cap) + shipments (qty)
- **Clustering:** because of utility, market, infrastructure (motor terminals, shops)
- **Rent VS Own:** time horizon, land, location,
- **Present VS Future:** not average, nor max $\rightarrow$ overflow qty/ inventory

Factors that affects site selection

- **Objective:** min cost, max distance (nuclear plant), max coverage (police)
- **Demands and Supplies:** big cities, community, cluster of 'things' (CDC, Gift)
- **Distribution and Growth:** traffic type (Bus Stop VS BTS station)
- **Infrastructure:** road, highway, water, electricity, data
- **Other:** land price, potential,
- **Regulation & Benefit:** BOI, zoning
  - **Must-Have:** water treatment, waterway, electricity
  - **Must-Avoid:** restricted/religious/historical areas, community
  - **Zone:** industrial park, land use zoning, flood plane, buffering
  - **Civic Codes:** EIA, EHIA, license

Questions for facility location

- How many facilities should there be?
- Where should they be located?
- How does each facility function together?

Theoretically, the question is strategic, multi-facet, and difficult to optimize $\rightarrow$ MILP, AHP, fuzzy logic

Practical Good news

- **Cluster:** city, population, airport, utility, workforce
- **Competitors:** e.g., Boots **VS** Watson, 7Eleven **VS** 'other'
- **Wait-And-See approach:** one warehouse/one building at a time
- **Issues:** expanding urban area, restricted zone

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