Lecture 1: Planning Problems and Supply Chain Design

TIØ4285 Production and Network Economics

Spring 2021

Note that the lecture is recorded and streamed through Panopto.

Norwegian University of Science and Technology

Outline

- Production and Network Economics vs. Industrial Optimization and Optimization Methods
- Hierarchical Planning
- Supply Chain Design
- Dealing with Uncertainty

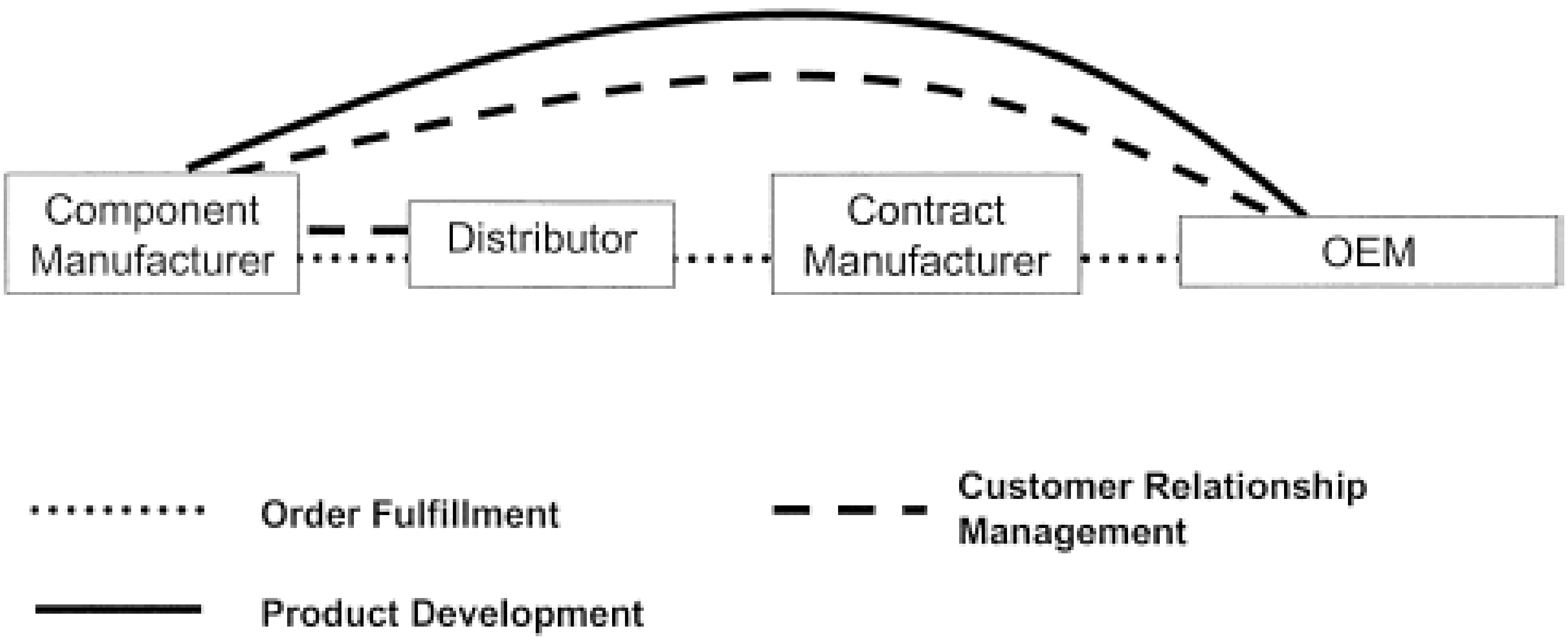
Production and Network Economics

- Focus on economical analysis and decision making in single companies and networks
- Strongly related to supply chain management, but with focus on the economic issues
- We will address mainly coordination and control issues with a particular focus on the interfaces between companies or divisions within companies.

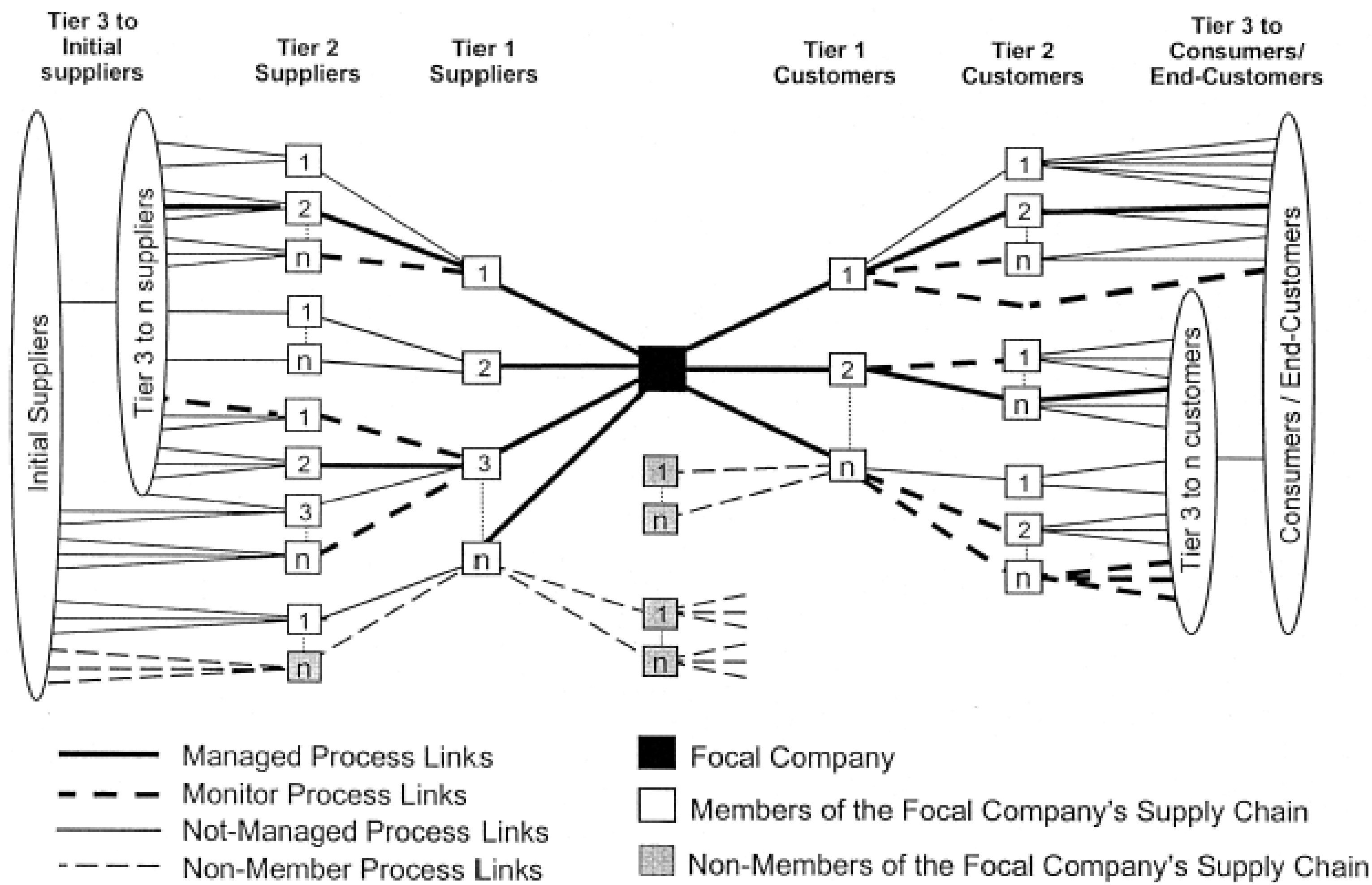
Table 1
A sample of definitions of supply chain management

Authors	Definition
Tan et al. (1998)	Supply chain management encompasses materials/supply management from the supply of basic raw materials to final product (and possible recycling and re-use). Supply chain management focuses on how firms utilise their suppliers' processes, technology and capability to enhance competitive advantage. It is a management philosophy that extends traditional intra-enterprise activities by bringing trading partners together with the common goal of optimisation and efficiency.
Berry et al. (1994)	Supply chain management aims at building trust, exchanging information on market needs, developing new products, and reducing the supplier base to a particular OEM (original equipment manufacturer) so as to release management resources for developing meaningful, long term relationship.
Jones and Riley (1985)	An integrative approach to dealing with the planning and control of the materials flow from suppliers to end-users.
Saunders (1995)	External Chain is the total chain of exchange from original source of raw material, through the various firms involved in extracting and processing raw materials, manufacturing, assembling, distributing and retailing to ultimate end customers.
Ellram (1991)	A network of firms interacting to deliver product or service to the end customer, linking flows from raw material supply to final delivery.
Christopher (1992)	Network of organisations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate consumer.
Lee and Billington (1992)	Networks of manufacturing and distribution sites that procure raw materials, transform them into intermediate and finished products, and distribute the finished products to customers.
Kopczak (1997)	The set of entities, including suppliers, logistics services providers, manufacturers, distributors and resellers, through which materials, products and information flow.
Lee and Ng (1997)	A network of entities that starts with the suppliers' supplier and ends with the customers' custom the production and delivery of goods and services.

Theory: Chain of Actors



Practice: Network of Actors

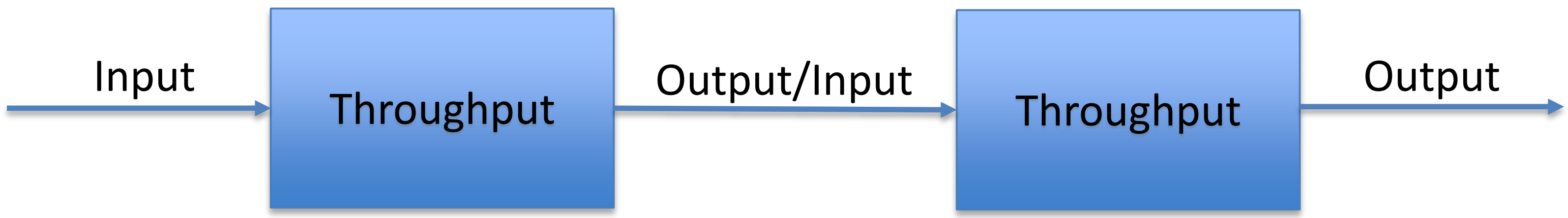


Optimization Perspective

- Usually either maximize output or minimize input (given the other)

Extending the System

- Let's extend the system under consideration (make it more of a network)



- What changes from an optimization point of view?
  - More variables
  - More constraints
  - Not that much else…

- Who is making decisions?
  - Still a single centralized decision maker

What happens if…

- The output depends on your decisions?
  - Market prices may change according to changes in supply
  - How do you model market power?

- The two different «Throughputs» belong to different decision makers?
  - Different independent companies?
  - Same company, different divisions (e.g. Norway vs. USA)?

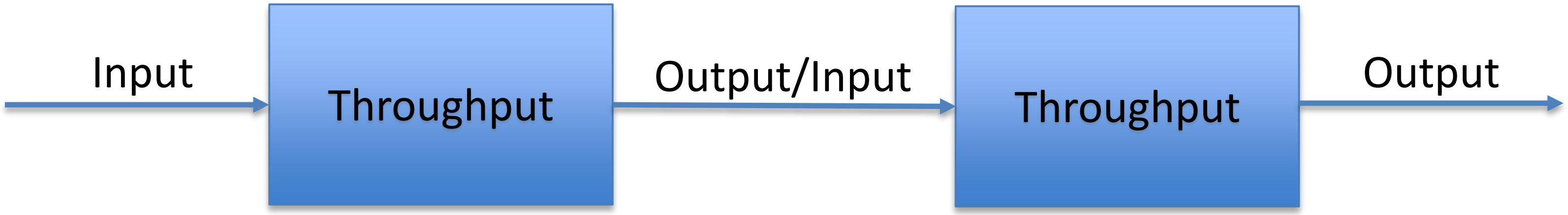
- How do you change the decision makers' behaviour?
  - To improve another company's result and/or joint profits?
  - For the benefit of «the greater good»?

Focus in this course I

- This course will consider problems for single decision makers
  - Supply Chain Design
  - Inventory Management
  - Distribution Planning

Focus in this course II

- But we will also consider decisions taken by different decision makers
  - Incentive mechnisms
  - Value of information
  - Asymmetric information
  - Principal-Agent problems



- And we will look in to how to model markets as this is where companies interact
  - Equilibrium modelling

Models and methods

- This course builds on (and has a certain overlap) with
  - TIØ4118 Industrial Economic Analysis
  - TIØ4130 Optimization Methods
- We will therefore use models and methods from both optimization and economics
  - Advantages and Disadvantages
  - Limitations

Planning and Decision Support

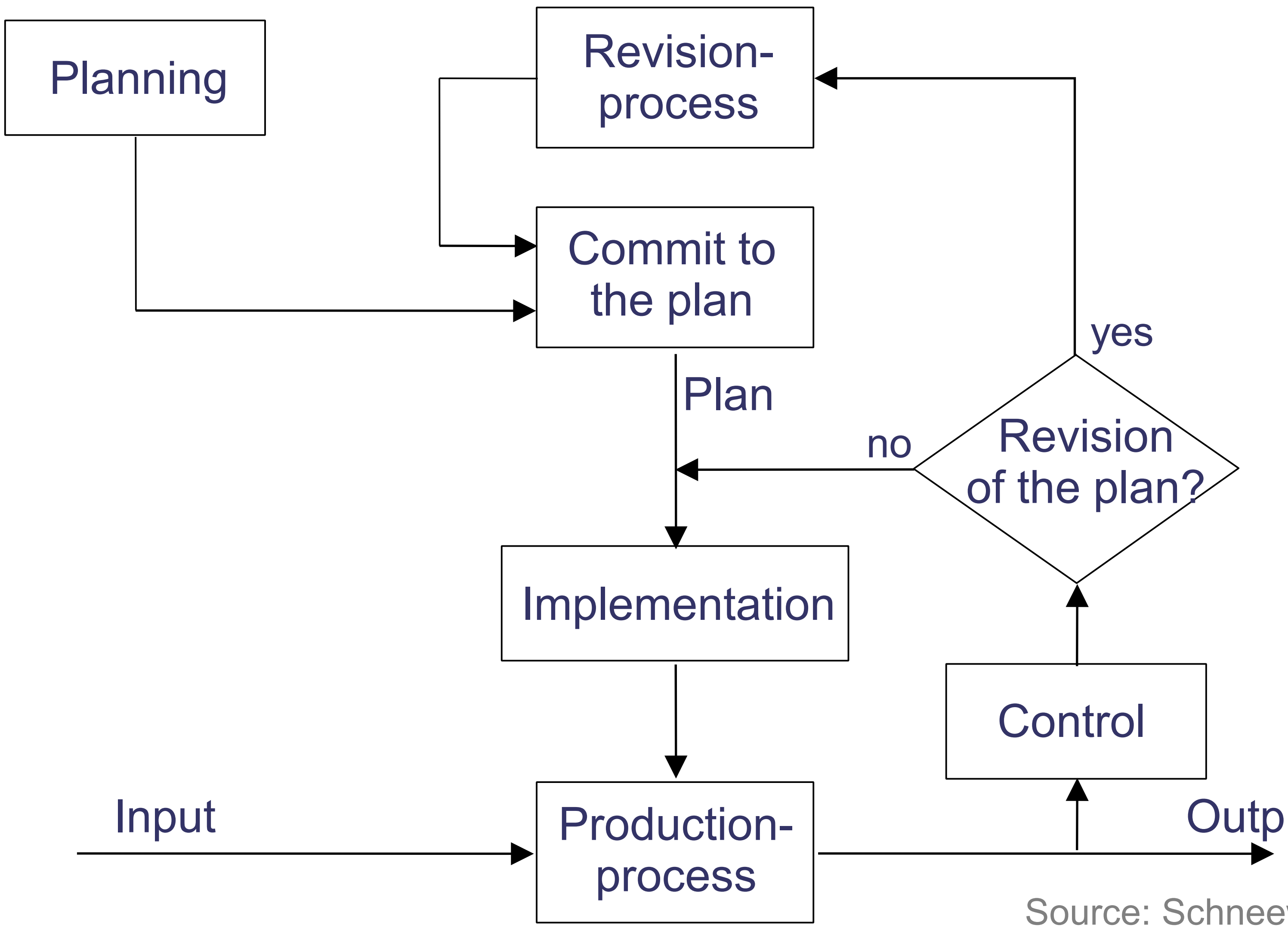
What is Planning?

- First statement:
  - Planning is a target-directed decision to take future action, it is therefore a decision process
  - Result of the decision process is a plan

- Second statement:
  - Planning is the activity of establishing goals over some future time period, called the planning horizon

- Third statement:
  - Planning is a complex social activity that cannot be simply structured by rules of thumb or quantitative procedures
  - Essence of planning is to organize, in a disciplined way, the major tasks that the firm has to address to maintain an operational efficiency in its existing businesses and to guide the organization into a new and better future

The Planning Process

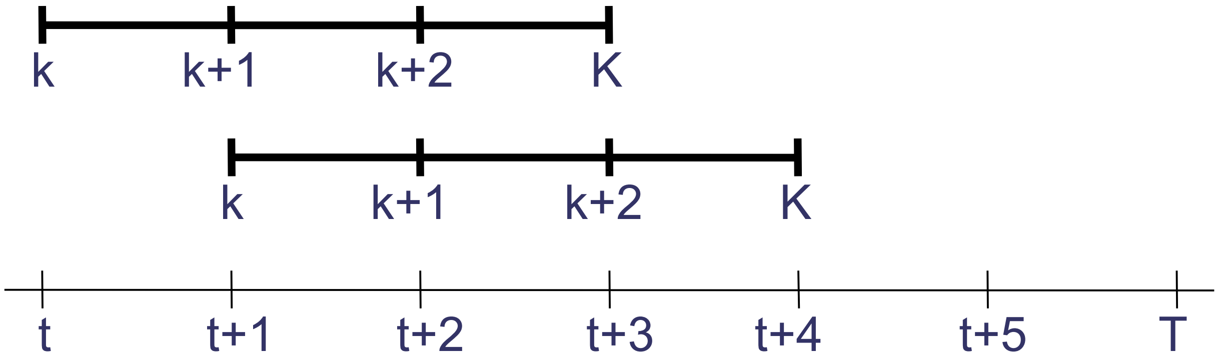


Source: Schneeweiß 1997

The Planning Horizon

- The planning horizon should be adjusted according to the effects of the decisions and the availability of reliable forecasts

- Rolling horizons can be used to incorporate dynamics and the possibility of learning in the decision process



- NB: optimal policies are very likely to turn out to be suboptimal in an ex-post analysis

Problems of the Deterministic Setting

- Rolling horizons are presented in every textbook on planning, usually in a deterministic setting
- Deterministic setting can not capture uncertainties in the future: flexible decisions are not made
- Flexibility (and options as well) never shows up in a deterministic solution, unless it comes free
- “You never buy an insurance in a deterministic world!”

Anthony's Framework

- Developed by Robert N. Anthony in 1965
- First framework to classify different planning and decision levels
- Originally, Anthony distinguished between
  - Strategic Planning
  - Management Control
  - Operational Control
- Today known as
  - Strategic Planning
  - Tactical Planning
  - Operational Planning

Popular picture of Anthony's framework

- Top management
- Long term perspective (5 – 10 years)
- Highly aggregated data

- Middle management
- Medium time horizon (3 months – 2 years)
- Less aggregated data

- Lower management
- Short time horizon (Days – 3 months)
- Disaggregated data

Comparing the 3 Planning Levels I

FACTOR	STRATEGIC PLANNING	TACTICAL PLANNING	OPERATIONAL PLANNING
Purpose	Management of change, resource acquisition	Resource utilization	Execution, evaluation, and control
Implementation instruments	Policies, objectives, capital investments	Budgets	Procedures, reports
Planning horizon	Long	Medium	Short
Scope	Broad, corporate level	Medium, plant level	Narrow, job shop level
Level of management involvement	Top	Middle	Low
Frequency of Replanning	Low	Medium	High

Comparing the 3 Planning Levels II

FACTOR	STRATEGIC PLANNING	TACTICAL PLANNING	OPERATIONAL PLANNING
Source of information	Largely external	External and internal	Largely internal
Level of aggregation of information	Highly aggregated	Moderately aggregated	Detailed
Required accuracy	Low	Medium	High
Degree of uncertainty	High	Medium	Low
Degree of risk	High	Medium	Low

Source: Hax/Candea 1984

Operational Control

- Some kind of fourth level within the framework
- Deals with the material flow in the plant, basically no planning horizon
- Focuses basically on “error management”, deviation from the plan due to unforeseen events (breakdown of production line, etc)
- Probably best covered by the Norwegian terms “styring” and “drift”

Implications of the Framework

- Decisions on the different levels cannot be made isolated of each other, there is a strong interaction
- Decisions at one level are linked to the decisions at a higher level. Lower level decisions have to satisfy constraints given from a higher level and allow in turn to evaluate the decisions from a higher level.
- Integrated approach is needed to avoid suboptimal solutions
- Decomposition (here: in terms of organization) is necessary to perform planning on the different levels, as one global approach will fail due to the complexity

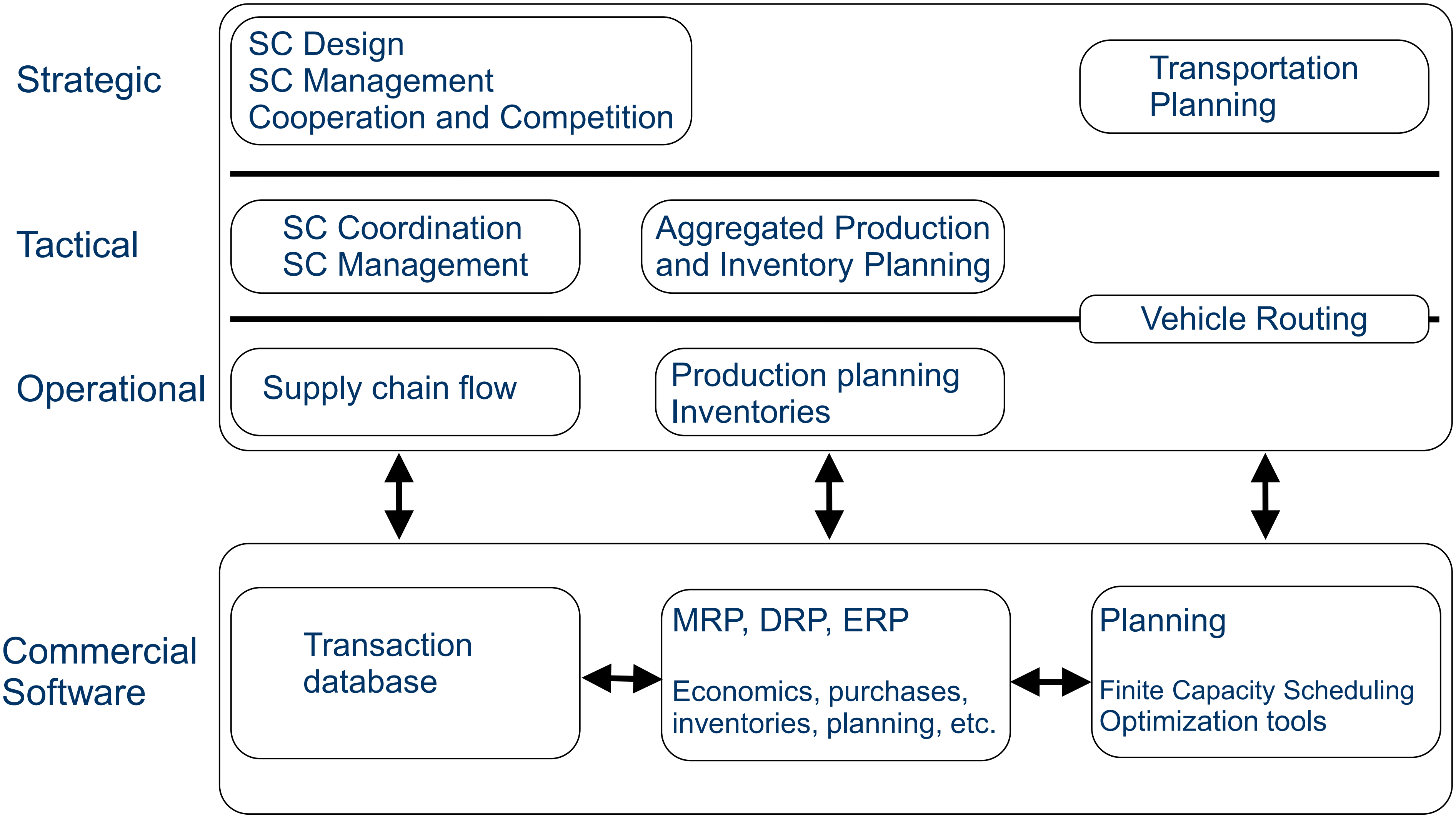
Decision Support Traditions

- Data processing/manipulation
  - MRP, DRP (little optimization)
- Mathematical programming
  - LP, MIP, Heuristics, Stochastic Programming
- Simulation
  - Discrete time simulation, system dynamics
- AI
  - Expert systems (rule based), constraint optimization, knowledge based rules, neighborhood search, machine learning

Hierarchical Planning and Operations Research

- Decisions are very complex, especially in a setting with many locations, plants, warehouses, machines, products, customers, etc. (not to talk about uncertainties of the future...)
- Decision support tools are therefore used to provide decision-makers with necessary support
- Most of today's decision support tools are based on optimization and methods of Operations Research

Supply Chain Management Packages



Optimization in supply chain network design

An example from Simchi-Levi et al. (2007)

Solution Techniques

- Mathematical optimization techniques:
  - Exact algorithms: find optimal solutions
  - Heuristics: find “good” solutions, not necessarily optimal

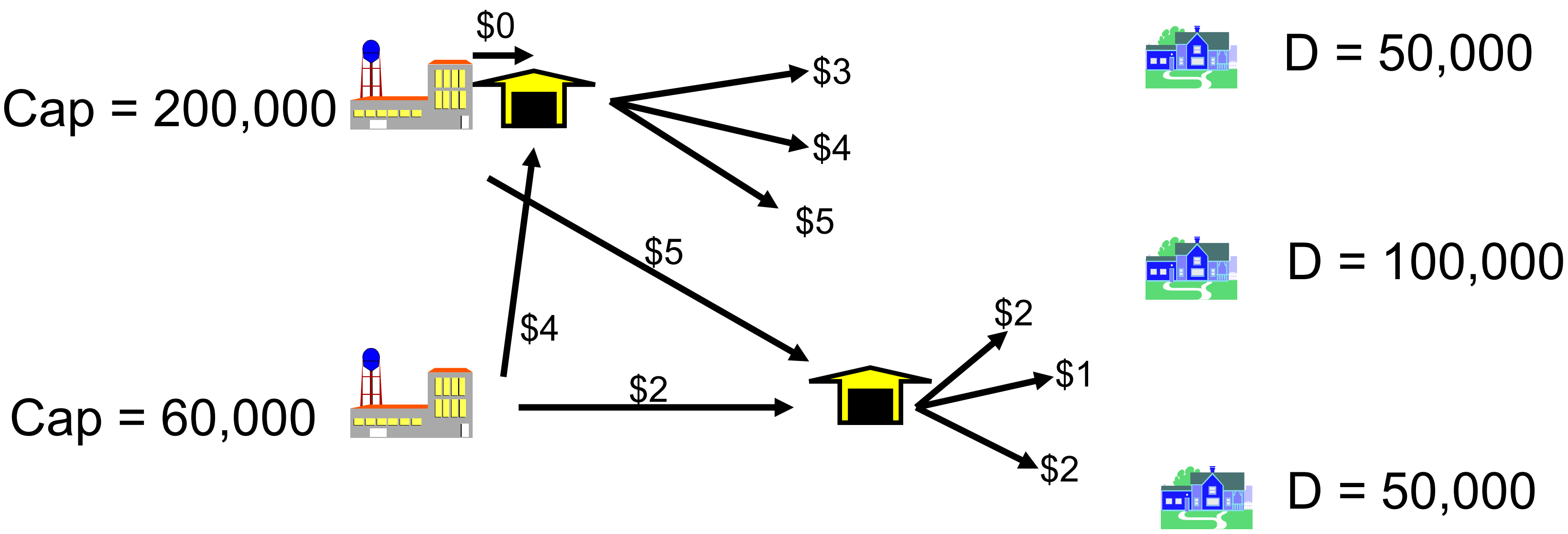
- Simulation models: provide a mechanism to evaluate specified design alternatives created by the designer.

Heuristics or exact algorithms?

Consider the production network for a single product:

- Two plants p1 and p2
  - Plant p1 has an annual capacity of 200,000 units.
  - Plant p2 has an annual capacity of 60,000 units.
- The two plants have the same production costs.
- There are two warehouses w1 and w2 with identical warehouse handling costs.
- There are three markets areas c1,c2 and c3 with demands of 50,000, 100,000 and 50,000, respectively.

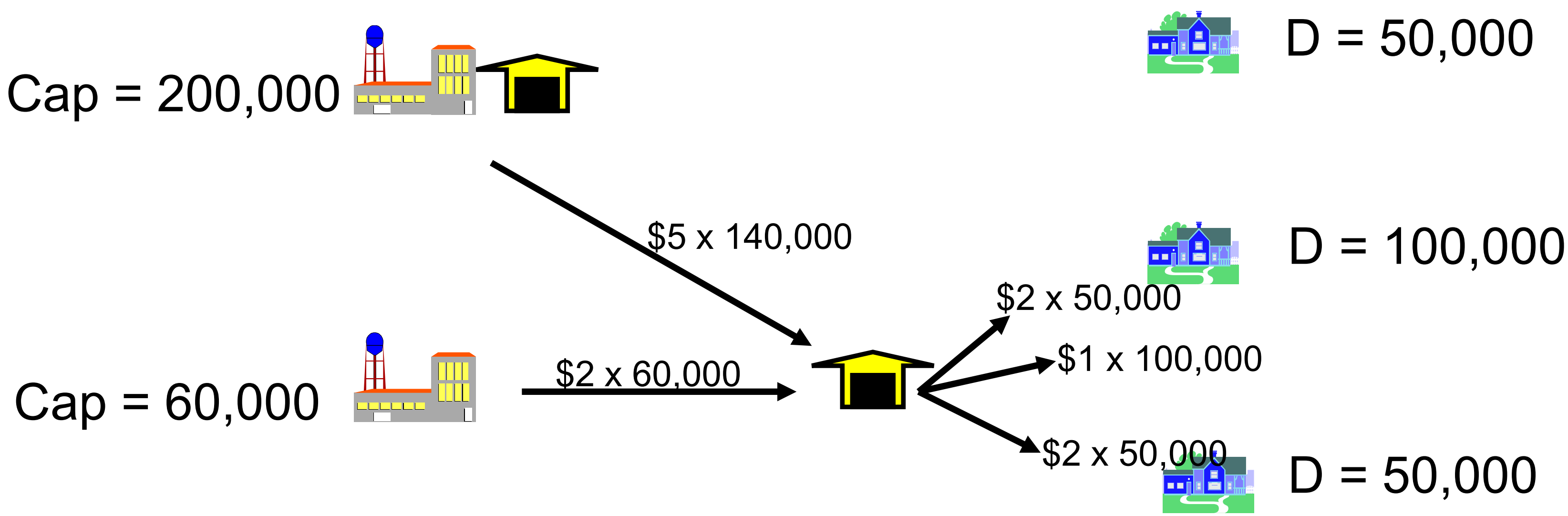
Why Optimization Matters?



Production costs are the same, warehousing costs are the same

Traditional Approach #1:

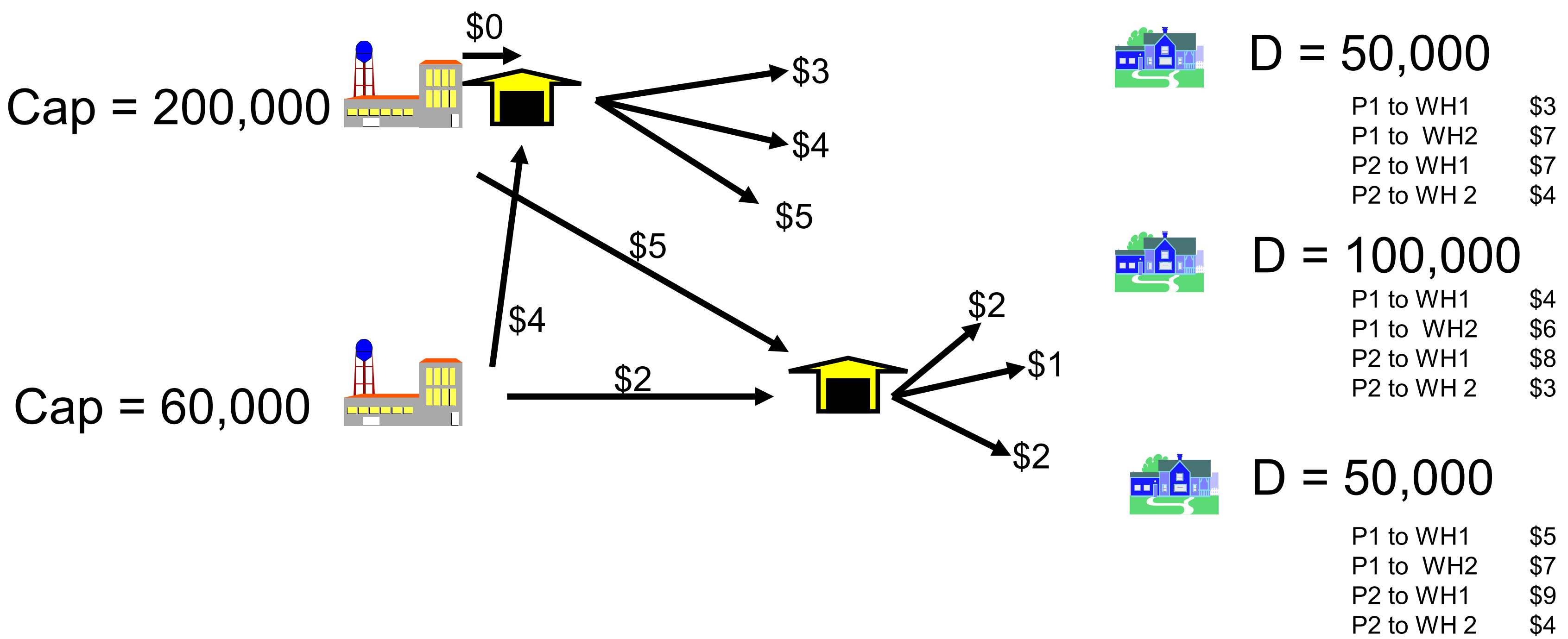
Assign each market to closet WH. Then assign each plant based on cost.



Total Costs = $1,120,000

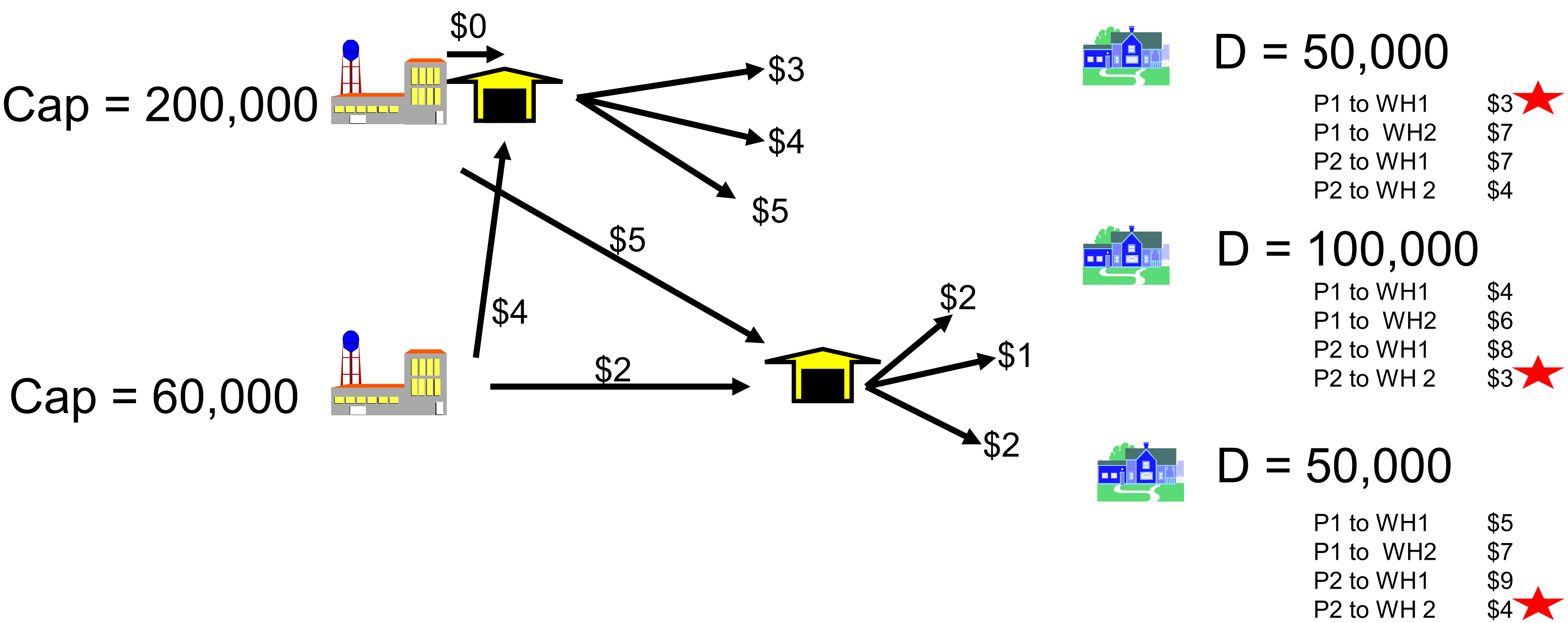
Traditional Approach #2:

Assign each market based on total landed cost



Traditional Approach #2:

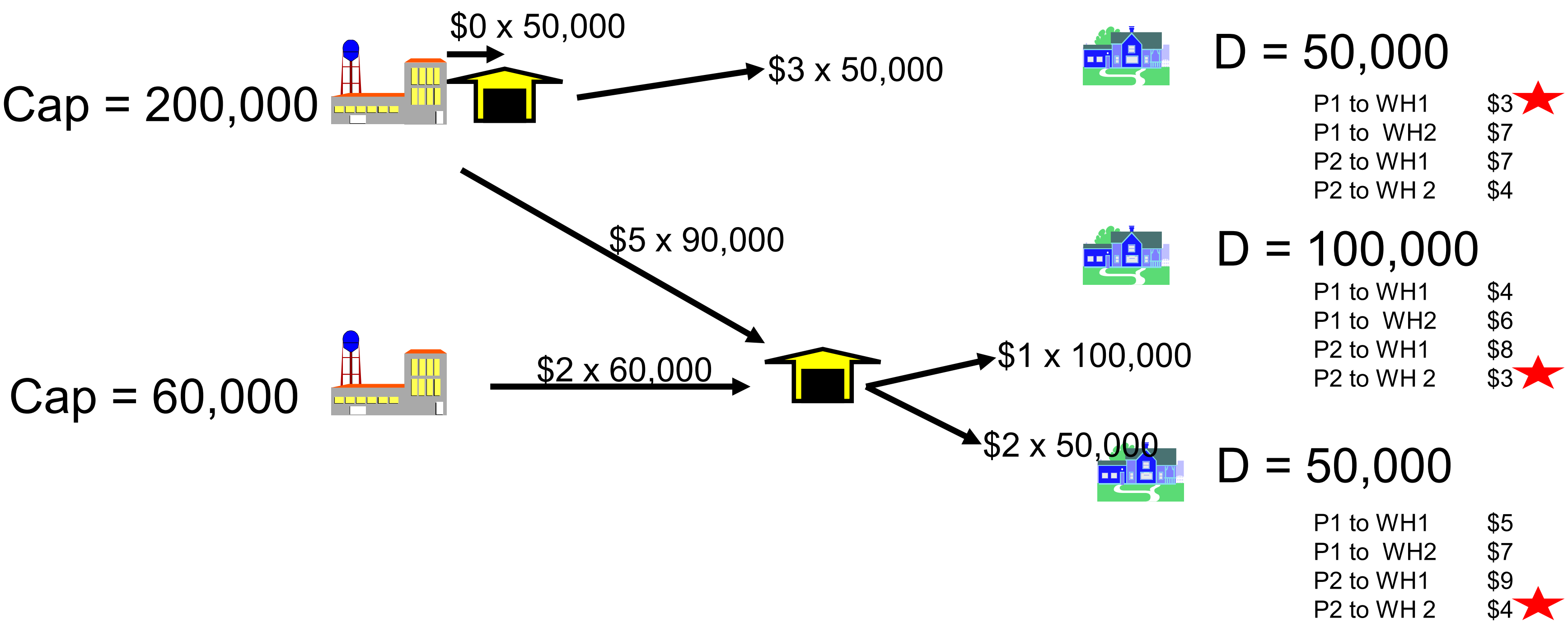
Assign each market based on total landed cost



Market #1 is served by WH1, Markets 2 and 3 are served by WH2

Traditional Approach #2:

Assign each market based on total landed cost



Total Cost = $920,000

The Optimization Model

- The problem can easily be formulated as a linear programming problem.

- Let
  - $x(p1, w1), x(p1, w2)$, $x(p2, w1)$, $x(p2, w2)$ be the flows from the plants to the warehouses.
  - $x(w1, c1), x(w1, c2)$, $x(w1, c3)$ be the flows from the warehouse w1 to customer zones c1, c2 and c3.
  - $x(w2, c1), x(w2, c2)$, $x(w2, c3)$ be the flows from warehouse w2 to customer zones c1, c2 and c3

Formulation

- We want to solve the following problem

$$\begin{aligned}\min 0x(p1,w1)&+5x(p1,w2)+4x(p2,w1)+2x(p2,w2)\\&+3x(w1,c1)+4x(w1,c2)+5x(w1,c3)\\&+2x(w2,c1)+1x(w2,c2)+2x(w2,c3)\end{aligned}$$

subject to

$$x(p2,w1)+x(p2,w2)\leq 60\,000$$
$$x(p1,w1)+x(p2,w1)=x(w1,c1)+x(w1,c2)+x(w1,c3)$$
$$x(p2,w1)+x(p2,w2)=x(w2,c1)+x(w2,c2)+x(w2,c3)$$
$$x(w1,c1)+x(w2,c1)=50\,000$$
$$x(w1,c2)+x(w2,c2)=100\,000$$
$$x(w1,c3)+x(w2,c3)=50\,000$$

and all flows greater than or equal to zero

Optimal Solution

- Distribute product according to the following plan

to from	W1	W2	C1	C2	C3
P1	140 000				
P2		60 000			
W1			50 000	40 000	50 000
W2				60 000	

- Total cost for the optimal solution is 740,000.

Facility Location under Economics of Scale

A Strategic Case from Gilde (Nortura)

Background

- Slaughterhouse location analysis

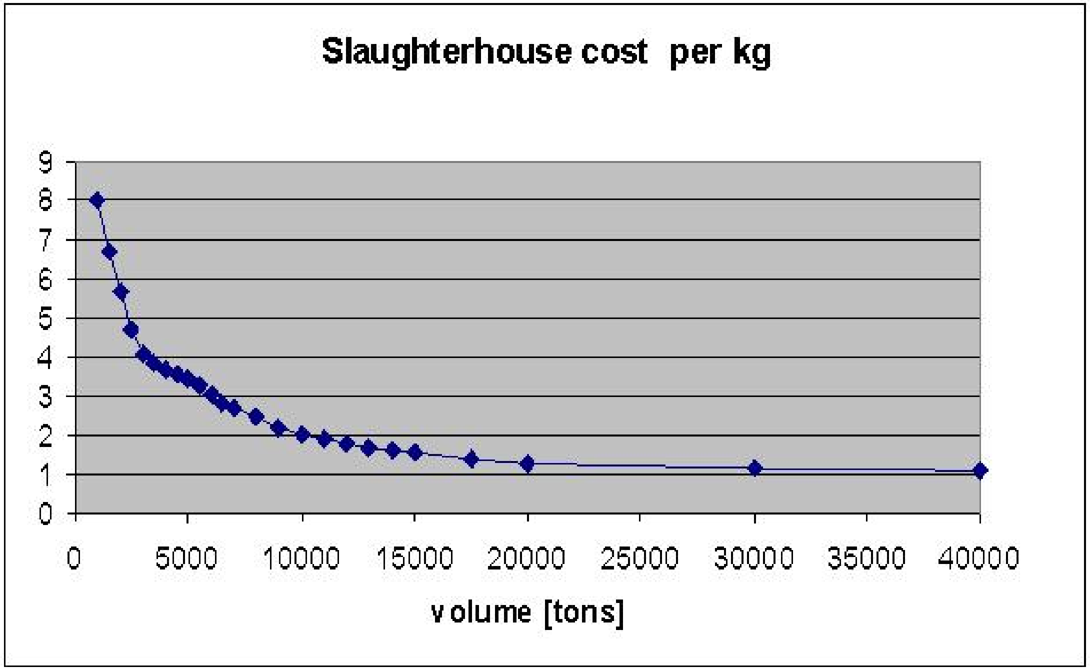
- The company has approximately 25 slaughterhouses for cattle

- What would be the optimal number and locations if they were free to replace them today (using the animal populations they are currently serving)?
  - Location
  - Size

- Requirements
  - All demand (from farmers) should be met
  - No animal should stay more than 8 hours in the car on its way to the slaughterhouse

Slaughterhouse Cost I

- Nonlinearities in objective
- Economics of Scale in slaughterhouses
- Numbers are from a German best practice study



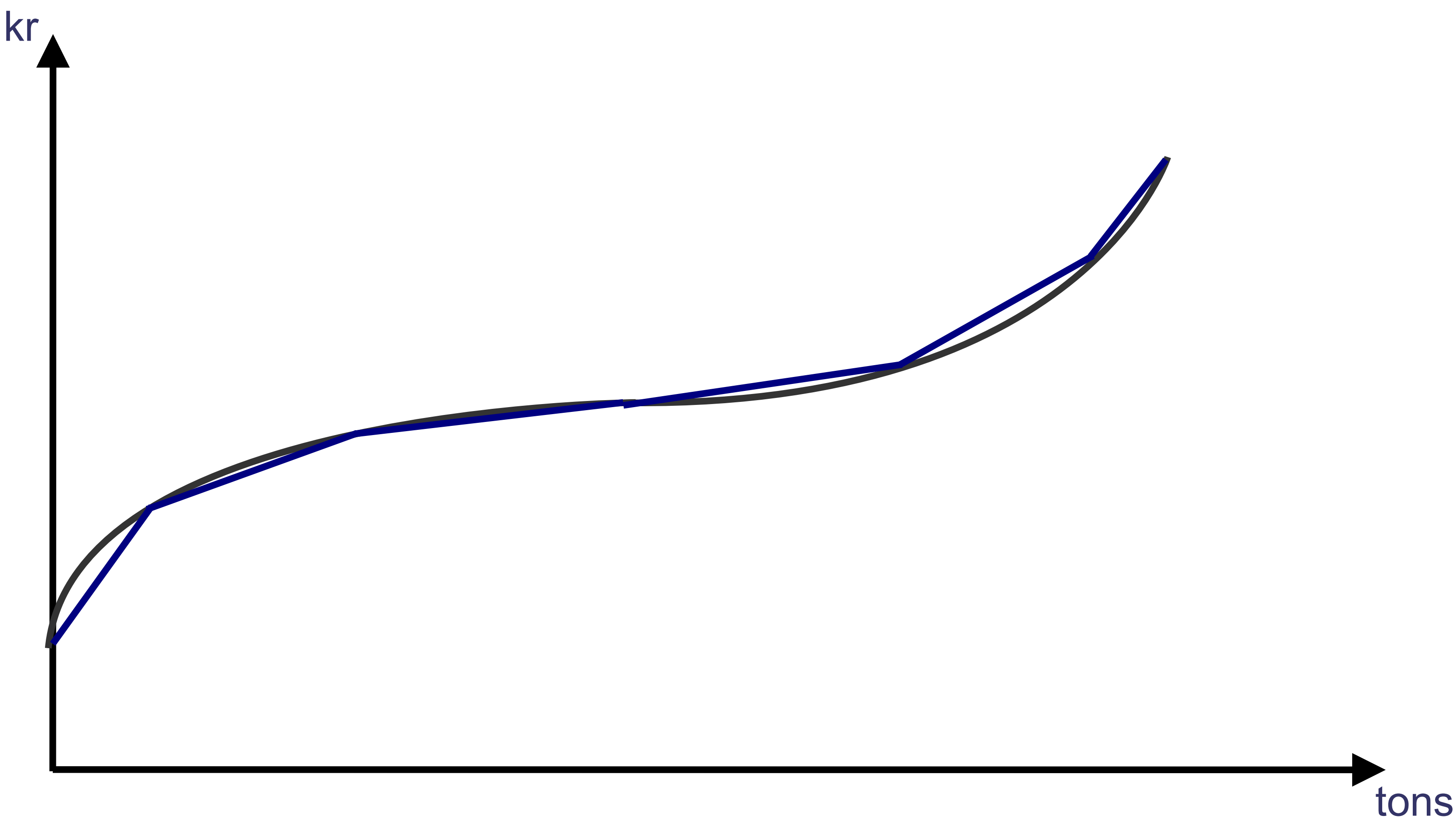
Slaughterhouse Cost II

- Includes
  - Fixed costs
    - Capital cost, Personal, Insurance
  - Variable costs
    - Energy, Personal, Water, Cleaning, Repairs, Classification, Material, Waste management,

- Broken down to yearly numbers and further down to cost per kilo

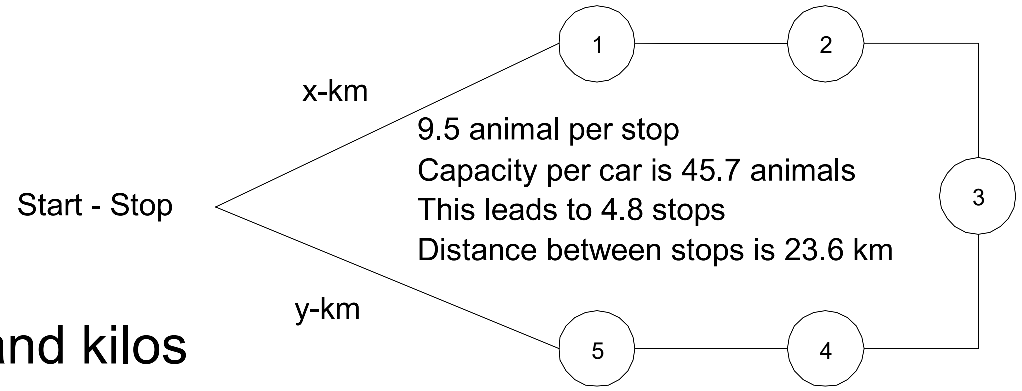
Total Slaughterhouse Costs

(without transportation)



Transportation Time and Cost Estimates

- Time
  - Time between slaughterhouse and region
  - Time on roundtrip within region
  - Terminal time
  - Max limit for transportation is 8 hours



- Cost
  - Linear in travel distance and kilos

- Both time and cost depend on the size of the car used

Notation

Sets

$\mathcal{B}$	Set of breakpoints of piecewise linear function approximating facility costs (i.e. blue line in slide 43)
$\mathcal{M}$	Set of municipalities

Parameters

A_i	Number of animals to be picked up in municipality i, $i \in \mathcal{M}$
C_{ij}	Cost of transporting one animal from municipality i to municipality j, $i \in \mathcal{M}, j \in \mathcal{M}$
g	Average weight of an animal
P_b	Total cost of breakpoint b of the piecewise linear function, $b \in \mathcal{B}$
Q_b	Total weight of breakpoint b of the piecewise linear function, $b \in \mathcal{B}$
T_{ij}	1 if animal can be transported within 8 hours from municipality i to municipality j, 0 otherwise, $i \in \mathcal{M}, j \in \mathcal{M}$

Decision Variables

x_{ij}	Number of animals transported from municipality i to municipality j, $i \in \mathcal{M}, j \in \mathcal{M}$
λ_{jb}	Weight of breakpoint b for municipality j, $j \in \mathcal{M}, b \in \mathcal{B}$

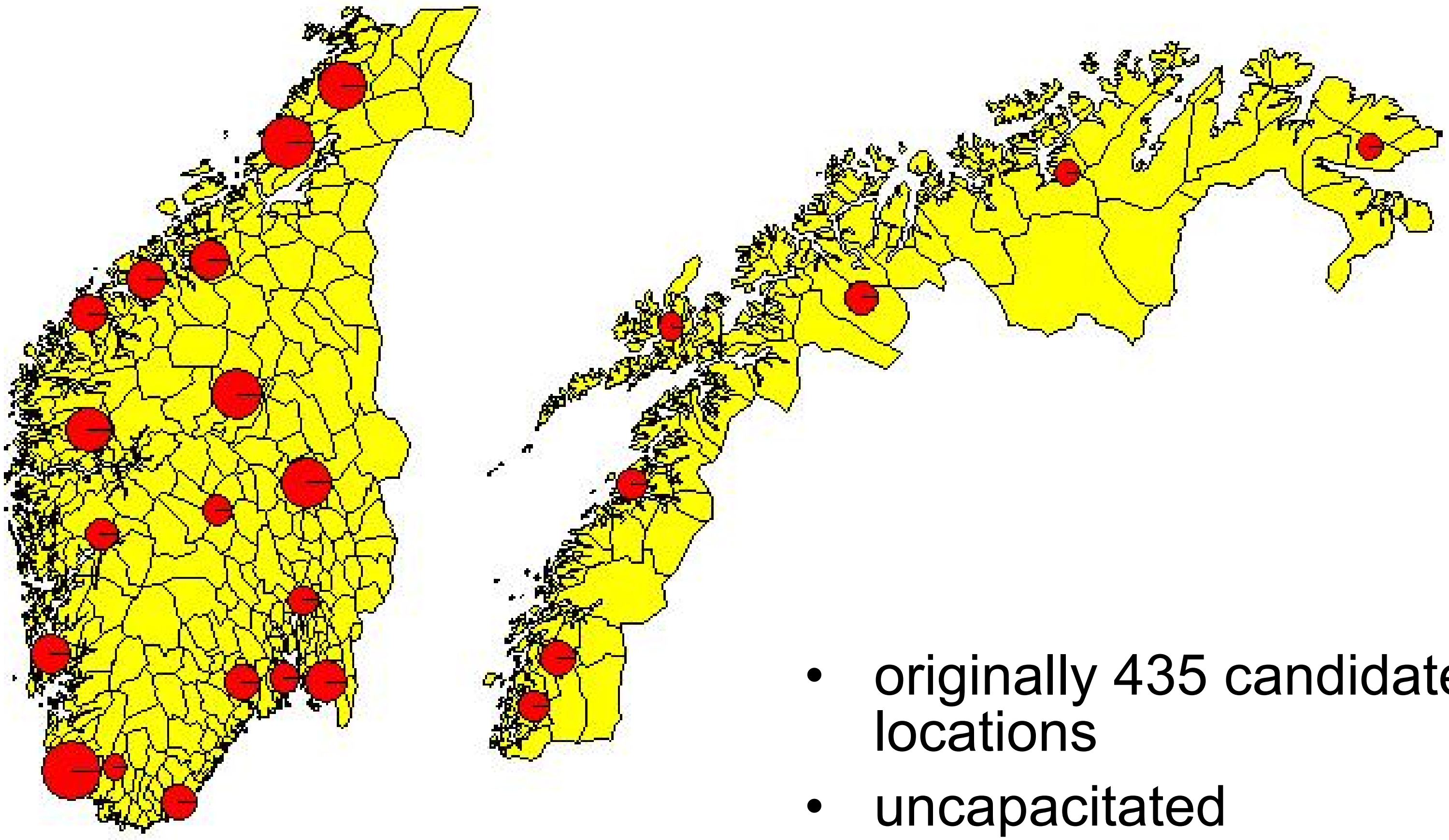
Facility Location Model

$$\min \sum_{i\in\mathcal{M}} \sum_{j\in\mathcal{M}} C_{ij}x_{ij} + \sum_{j\in\mathcal{M}} \sum_{b\in\mathcal{B}} Q_b P_b \lambda_{jb}$$

subject to

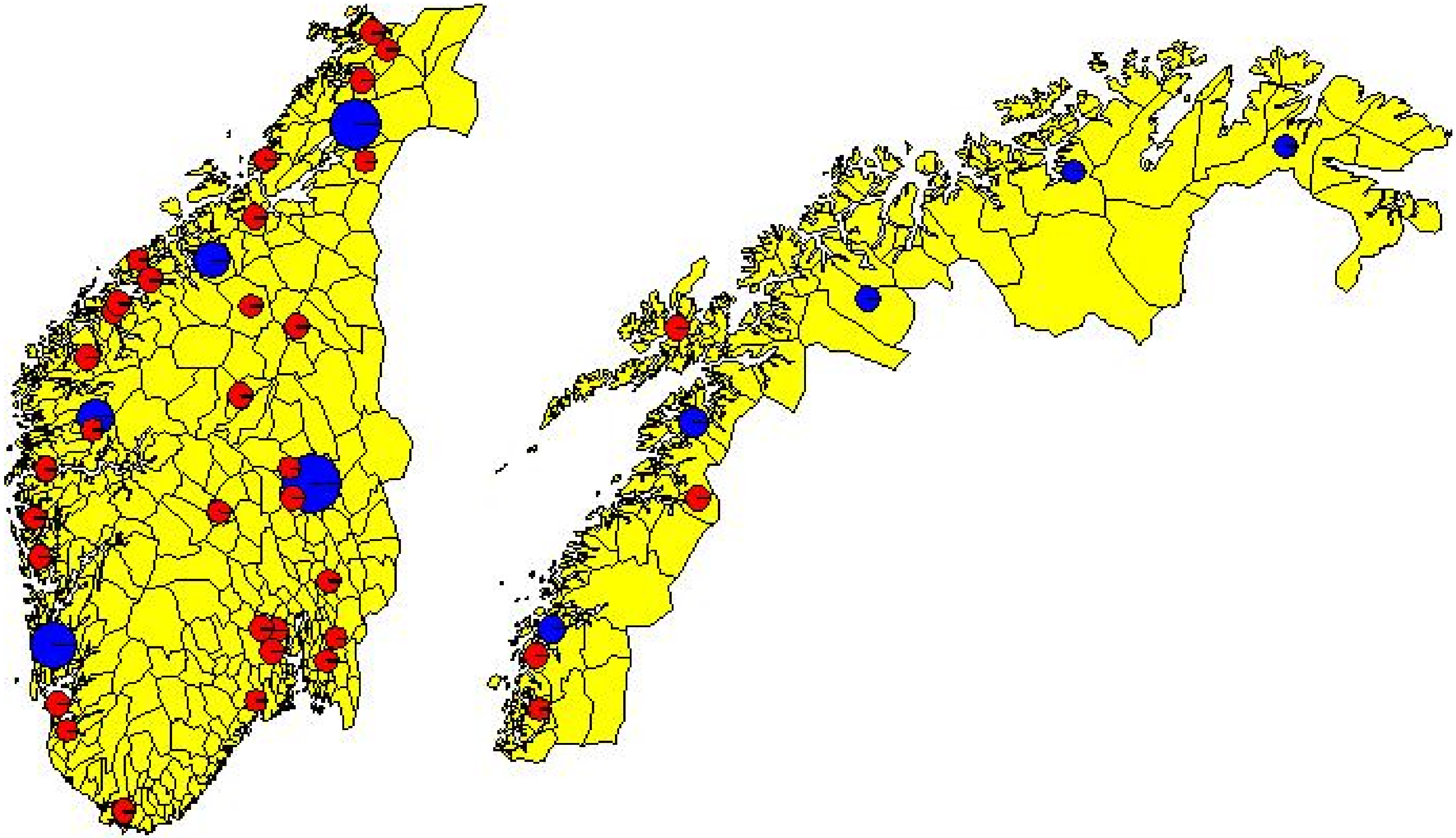
$$\begin{aligned}
\sum_{b\in\mathcal{B}} Q_b\lambda_{jb} &= g\sum_{i\in\mathcal{M}} x_{ij} && j\in\mathcal{M},\\
\sum_{b\in\mathcal{B}} \lambda_{jb} &= 1 \quad \text{(S2)} && j\in\mathcal{M},\\
\sum_{j\in\mathcal{M}} x_{ij} &= A_i && i\in\mathcal{M},\\
x_{ij} &\le T_{ij}A_i && (i,j)\in(\mathcal{M}\times\mathcal{M}),\\
x_{ij} &\ge 0 && (i,j)\in(\mathcal{M}\times\mathcal{M}),\\
\lambda_{jb} &\ge 0 && j\in\mathcal{M}, b\in\mathcal{B}.
\end{aligned}$$

Original Locations



- originally 435 candidate locations
- uncapacitated

Typical Result
(in this case on artificial data)



Results

- Best solution found has 11 slaughterhouses
  - Original solution has 25
- Reduces costs with 30%
- Optimality gap :(UB-LB)/UB =27%
- Solution time about 12 hours!

How should the model be used?

- The models indicates a potential for saving in today's situation
- It does not indicate what should be the future structure
- It indicates that the number of slaughterhouses is more important to the overall cost than the exact location is
- There are many almost equally good solutions with the same number of slaughterhouses, but where the geographical distribution is different.

How to deal with data: Aggregating Customers

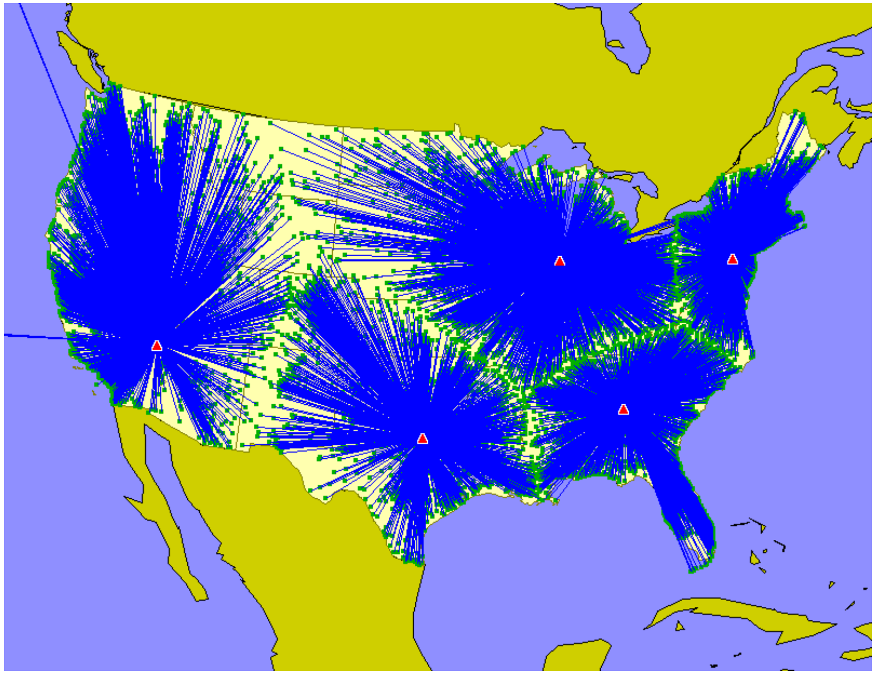
- Customers located in close proximity are aggregated using a grid network or clustering techniques. All customers within a single cell or a single cluster are replaced by a single customer located at the centroid of the cell or cluster.

  We refer to a cell or a cluster as a customer zone.

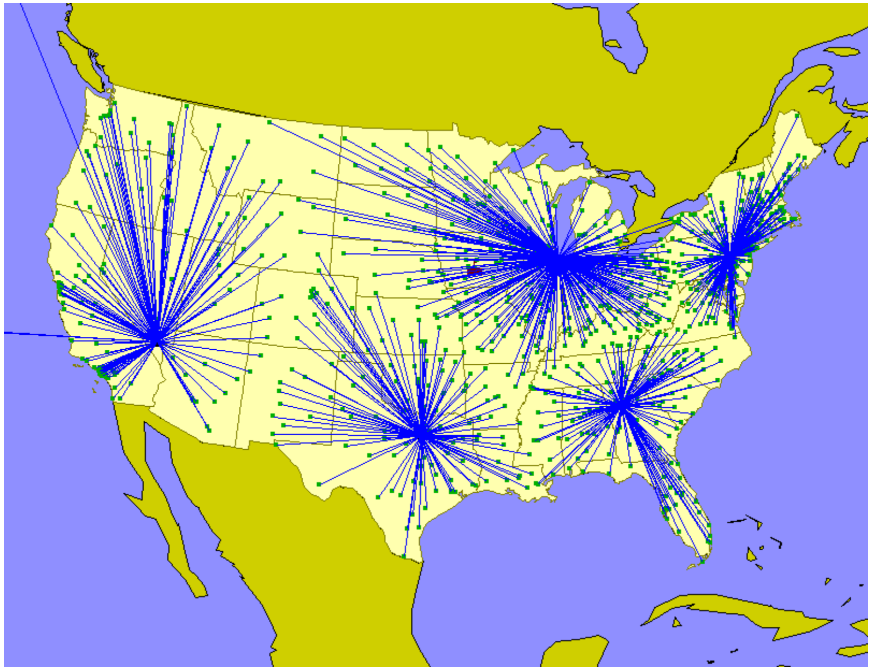
- Why?
  - The cost of obtaining and processing data
  - The form in which data is available
  - The size of the resulting location model
  - The accuracy of forecast demand

Comparing Output

Total Cost:$5,796,000
Total Customers: 18,000



Total Cost:$5,793,000
Total Customers: 800



Cost Difference < 0.05%

How to deal with data: Product Grouping

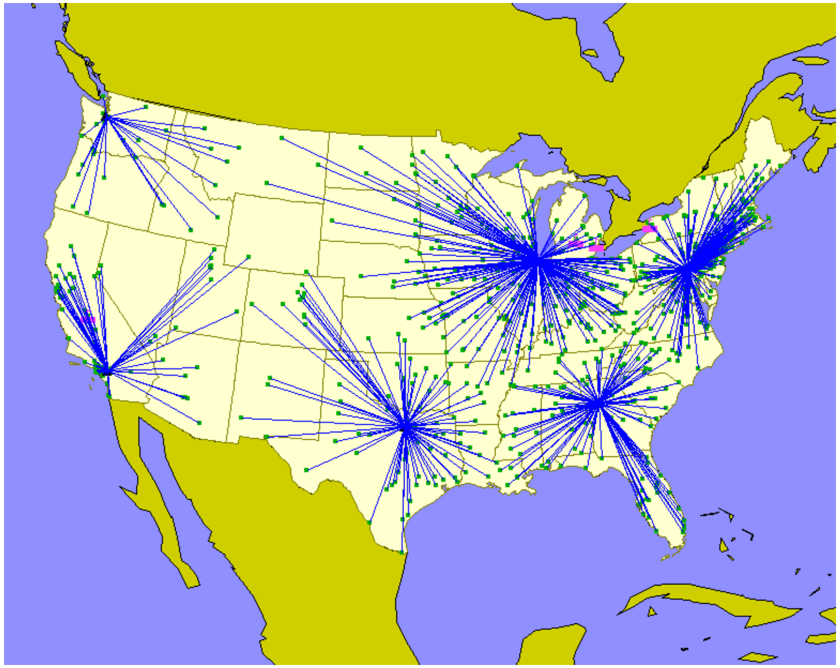
- Companies may have hundreds to thousands of individual items in their production line
  - Variations in product models and style
  - Same products are packaged in many sizes

- Collecting all data and analyzing it is impractical for so many product groups

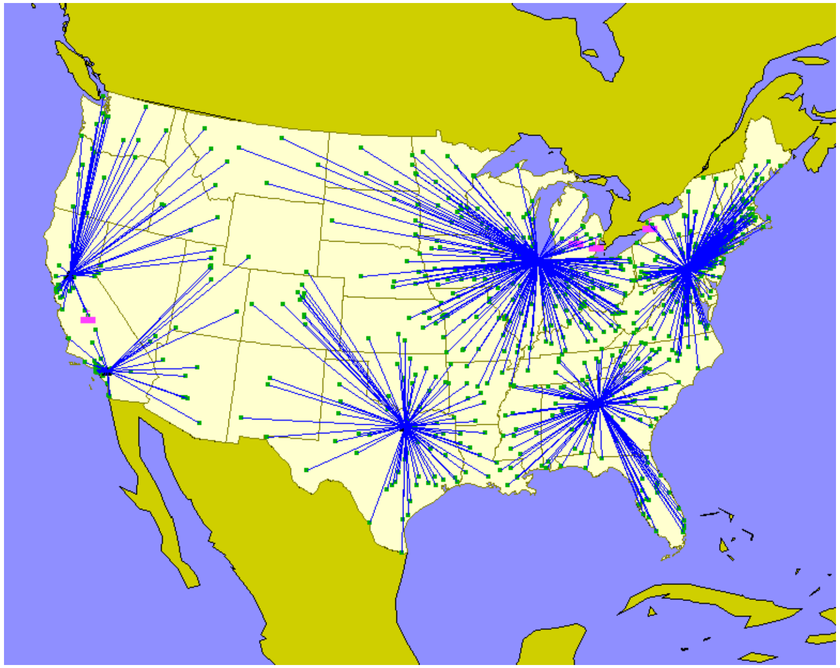
- Aggregate the products by similar logistics characteristics
  - Weight
  - Volume
  - Holding Cost

Sample Aggregation Test: Product Aggregation

Total Cost:$104,564,000
Total Products: 46



Total Cost:$104,599,000
Total Products: 4



Cost Difference: 0.03%

Returning to the slaughterhouses…

- Facility location problems are usually strategic problems
  - Long time horizons
  - Highly aggregated data

- Yet, we only consider 1 scenario: the present

- What happens if the future is different from the present?
  - Would it help to consider more scenarios?

A small example

- Consider the following optimization problem:

$$\max 3x + 2y + z$$

subject to

$$\begin{aligned} x &\leq \xi \\ y &\leq 1 - \xi \\ x + y + z &\leq 1 \\ x, y, z &\geq 0 \end{aligned}$$

where ξ is (for now) a known parameter.

- What is the optimal solution for any given ξ?

The impact of uncertainty I

- Assume now, you have to decide upon *x*, *y* and *z* before you know ξ

- Assume further that ξ is uniformly distributed on [0,1]

- Any suggestions for how to solve this problem?
  - Let's first solve the problem for every realization
  - Then check the solutions for other realizations and pick the one the performs best

- What happens if we evaluate a solution for any other possible realization (i.e. all scenarios)?

The impact of uncertainty II

- The solution is infeasible for every realization that is different from ξ (i.e. the value used to find the solution)
  - This is valid for any ξ!

- What if we had chosen z=1?
  - Why is this happening?

- In face of uncertainty: scenario analysis (deterministic optimization) may not produce good solutions, but it can evaluate the performance of solutions (= simulation)!

Modeling for uncertainty

- Let's provide some context for the small example:
  - ξ is uncertain demand
  - *x*, *y* and *z* are production decisions (taken before demand is known)

- Can you fix the model?