KS SUPPLY CHAIN FUNDAMENTALS

11 Location, Network and Distribution Planning

SS 2025

JKU
PLM Institute of
Production and
Logistics Management

Learning goals

After this lecture you should ...

- ... understand the importance of location decisions.
- ... be able to formulate and solve simple location problems.
- ... be able to formulate the transportation problem and solve it heuristically.
- ... know about current supply chain trends.

Literature

Stevenson, WJ: Operations Management. McGraw-Hill Education Ltd; latest edition - Chapter 8

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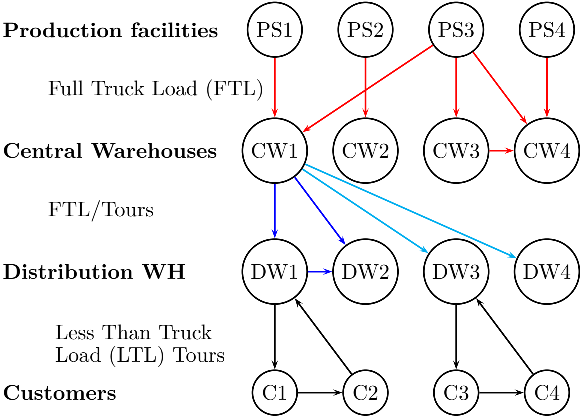
Introduction

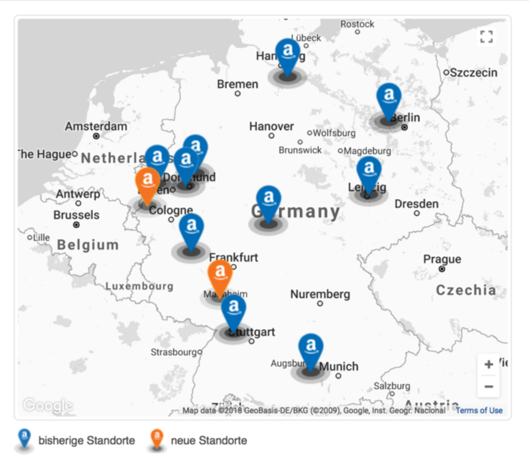
- Location decisions are strategic.
- Most of the time, additional facilities are added (e.g., a new store, a new production facility, a new storage facility)
- Depending on the kind of facility, different criteria have to be considered.
- Bad location decisions can lead to high transportation costs, lack of appropriately skilled labor, lack of resource availability, ...
- Usually, multiple feasible locations are identified and a choice is made between them (e.g., selecting one or multiple countries, then a region, then a selection of smaller communities and actual location alternatives).

Distribution networks



How many storage facilities should be built?
What kind of storage facilities should be built?
What should the transportation network look like?

Example Amazon



Source: http://www.amazon-logistikblog.de/standorte/ (Mar 2018)

Currently (2020) there are 15 distribution centers in Germany.

Since 2017 robots/AI is used in the logistics centers. Example: Mönchengladbach: `https://www.youtube.com/watch?v=7ZjB7tbCWEc` (DE) `https://youtu.be/2lIdVQbDmXM?feature=shared` (EN)

Logistics centers worldwide: `https://www.mwpvl.com/html/amazon_maps.html`

Example Spar

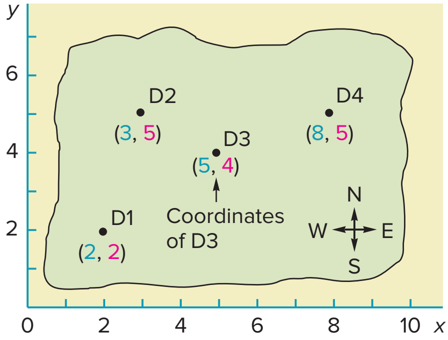
"SPAR delivers to 1600 locations in Austria every day. A sophisticated logistics planning tool ensures that all goods arrive at the stores at the right time and in the right amount."

`https://www.spar.at/nachhaltigkeit/energie-umwelt/transport-warenlogistik?icid=sca`

Source: `https://www.spar.at/nachhaltigkeit/energie-umwelt/transport-warenlogistik?icid=sca` (Jan 2020)

Locating a single facility: minimizing weighted distance

Find the best coordinates (x^*, y^*) for a new production facility. Every location is possible.



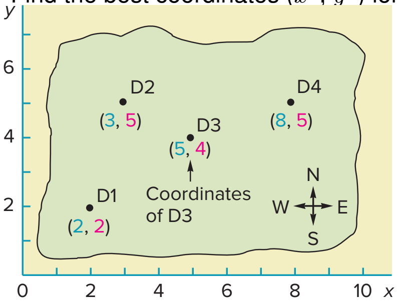
Stevenson (2017)

Destination i	x_i	y_i	Demand D_i
D1	2	2	800
D2	3	5	900
D3	5	4	200
D4	8	5	100
			2000

$n = 4$ Destinations (Customers)

Locating a single facility: minimizing weighted distance

Find the best coordinates (x^*, y^*) for a new production facility.



Stevenson (2017)

Destination i	x_i	y_i	Demand D_i
D1	2	2	800
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D3	5	4	200
D4	8	5	100
			2000

n Destinations (Customers)

Center of gravity (COG): Minimize the weighted squared distances.

$$x^* = \sum_{i=1}^n x_i D_i / \sum_{i=1}^n D_i$$
$$x^* = \frac{2\cdot 800 + 3\cdot 900 + 5\cdot 200 + 8\cdot 100}{2000} = 3{,}05$$
$$y^* = \sum_{i=1}^n y_i D_i / \sum_{i=1}^n D_i$$
$$y^* = \frac{2\cdot 800 + 5\cdot 900 + 4\cdot 200 + 5\cdot 100}{2000} = 3{,}7$$

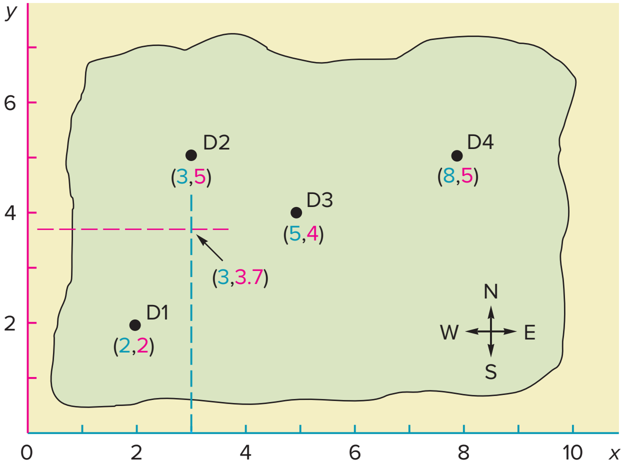
Steiner-Weber-Problem: Minimize the weighted Euclidean distances.

$$\min \sum_{i=1}^n D_i \sqrt{(x^* - x_i)^2 + (y^* - y_i)^2}$$

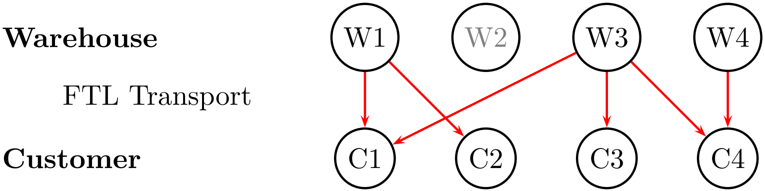
Solution using **Excel Solver**: $x^* = 3$, $y^* = 5$

Locating a single facility: minimizing weighted distance

Solution to Center of Gravity



Selecting p locations: p median problem



m possible locations are available, of which p can be selected, to supply n customers.

The cost of delivery to customer i from location j is c_{ij} euros.

The objective is to minimize the total costs.

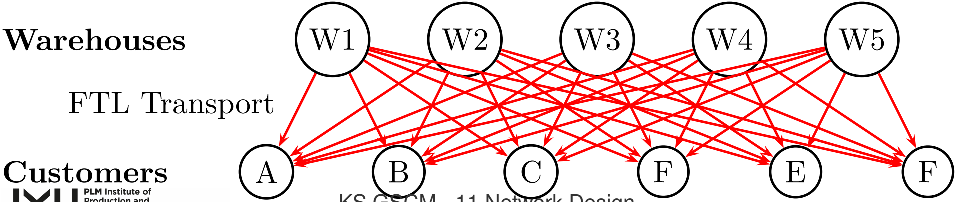
Example

There are m = 5 potential locations for storage facilities (1, 2, 3, 4 und 5), p = 3 should be chosen, to deliver to n = 6 customers (A, B, C, D, E and F). The following table depicts the cost of delivery from location i to customer j.

i,j	A	B	C	D	E	F
1	1	2	10	9	6	7
2	2	9	0	7	3	6
3	7	6	1	5	3	10
4	6	5	10	2	6	3
5	6	4	6	3	7	2

This problem can be formulated as a linear program with binary decision variables. The decisions that need to be made are:

- Which p locations should be chosen? (yes/no for each location)
- Which location should deliver to which customer?



Example: Decision variables

Decision variables:

$y_1, y_2, y_3, y_4, y_5 \in \{0, 1\}$

(1, if a location is chosen, 0 otherwise.)

If $y_2 = 1$, then location 2 is built/used.

If $y_2 = 0$, then location 2 is not built/used.

$x_{1A}, x_{1B}, x_{1C}, x_{1D}, x_{1E}, x_{1F},$

$x_{2A}, x_{2B}, x_{2C}, x_{2D}, x_{2E}, x_{2F},$

$x_{3A}, x_{3B}, x_{3C}, x_{3D}, x_{3E}, x_{3F},$

$x_{4A}, x_{4B}, x_{4C}, x_{4D}, x_{4E}, x_{4F},$

$x_{5A}, x_{5B}, x_{5C}, x_{5D}, x_{5E}, x_{5F}, \in \{0, 1\}$

$x_{1A} = 1$ means that location 1 delivers to customer A.

$x_{1A} = 0$ means that location 1 does not deliver to customer A.

Example: Model (1)

Minimize the total costs:

$$
\begin{aligned}
\text{min } & 1x_{1A} + 2x_{1B} + 10x_{1C} + 9x_{1D} + 6x_{1E} + 7x_{1F} + \\
& 2x_{2A} + 9x_{2B} + 0x_{2C} + 7x_{2D} + 3x_{2E} + 6x_{2F} + \\
& 7x_{3A} + 6x_{3B} + 1x_{3C} + 5x_{3D} + 3x_{3E} + 10x_{3F} + \\
& 6x_{4A} + 5x_{4B} + 10x_{4C} + 2x_{4D} + 6x_{4E} + 3x_{4F} + \\
& 6x_{5A} + 4x_{5B} + 6x_{5C} + 3x_{5D} + 7x_{5E} + 2x_{5F}
\end{aligned}
$$

Constraints (1)

Exactly three locations should be built:

$$y_1 + y_2 + y_3 + y_4 + y_5 = 3$$

Example: Model (2)

Constraints (2)

Each customer has to be served:

$$
\begin{aligned}
x_{1A} + x_{2A} + x_{3A} + x_{4A} + x_{5A} &= 1 \\
x_{1B} + x_{2B} + x_{3B} + x_{4B} + x_{5B} &= 1 \\
x_{1C} + x_{2C} + x_{3C} + x_{4C} + x_{5C} &= 1 \\
x_{1D} + x_{2D} + x_{3D} + x_{4D} + x_{5D} &= 1 \\
x_{1E} + x_{2E} + x_{3E} + x_{4E} + x_{5E} &= 1 \\
x_{1F} + x_{2F} + x_{3F} + x_{4F} + x_{5F} &= 1
\end{aligned}
$$

Only a location that is built/used can deliver to a customer:

$$
\begin{array}{cccccc}
x_{1A} \leq y_1, & x_{1B} \leq y_1, & x_{1C} \leq y_1, & x_{1D} \leq y_1, & x_{1E} \leq y_1, & x_{1F} \leq y_1, \\
x_{2A} \leq y_2, & x_{2B} \leq y_2, & x_{2C} \leq y_2, & x_{2D} \leq y_2, & x_{2E} \leq y_2, & x_{2F} \leq y_2, \\
x_{3A} \leq y_3, & x_{3B} \leq y_3, & x_{3C} \leq y_3, & x_{3D} \leq y_3, & x_{3E} \leq y_3, & x_{3F} \leq y_3, \\
x_{4A} \leq y_4, & x_{4B} \leq y_4, & x_{4C} \leq y_4, & x_{4D} \leq y_4, & x_{4E} \leq y_4, & x_{4F} \leq y_4, \\
x_{5A} \leq y_5, & x_{5B} \leq y_5, & x_{5C} \leq y_5, & x_{5D} \leq y_5, & x_{5E} \leq y_5, & x_{5F} \leq y_5.
\end{array}
$$

Example: Model (3)

The decision variables are binary:

$$
\begin{aligned}
y_i &\in \{0,1\} && \forall i \in \{1,2,3,4,5\}, \\
x_{ij} &\in \{0,1\} && \forall i \in \{1,2,3,4,5\}, j \in \{A,B,C,D,E,F\}
\end{aligned}
$$

$\rightarrow$Solution using Excel Solver

Model: General

Sets and parameters

I	set of potential locations (index i, $\lvert I \rvert = m$)
J	set of potential customers (index j, $\lvert V \rvert = n$)
c_{ij}	delivery cost from location i to customer j
p	number of locations to be built

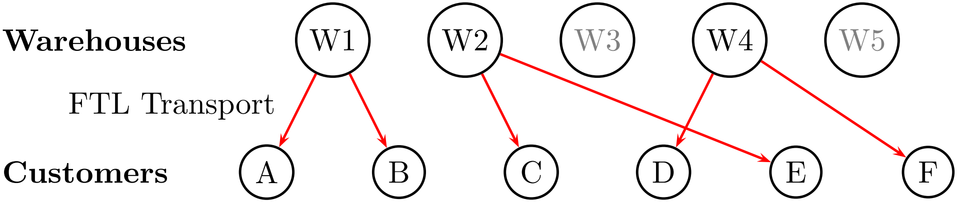
Decision variables

$y_i \in \{0,1\}$	whether location i is built (1) or not (0)
$x_{ij} \in \{0,1\}$	whether location i delivers to customer j (1) or not (0)

$$
\begin{aligned}
\min \sum_{i \in I} \sum_{j \in J} c_{ij} x_{ij} & & \\
\text{s.t.} \sum_{i \in I} y_i = p & & \\
\sum_{i \in I} x_{ij} = 1 & & \forall j \in J \\
x_{ij} \leq y_i & & \forall i \in I, j \in J \\
y_i \in \{0,1\} & & \forall i \in I \\
x_{ij} \in \{0,1\} & & \forall i \in I, j \in J
\end{aligned}
$$

Example: Solution

Build warehouses at locations 1, 2 and 4.



i,j	A	B	C	D	E	F
1	**1**	**2**	10	9	6	7
2	2	9	**0**	7	**3**	6
4	6	5	10	**2**	6	**3**

Costs: 11

Designing a distribution network

Locations and customers are fixed. Customers have a demand, locations a capacity. Which customer should get what amount from which location? Known as **transportation problem**.

Example: transportation cost matrix per unit:

	Customers				
Facility location	A	B	C	D	Capacity
F1	10	5	6	11	25
F2	1	2	7	4	25
F3	9	1	4	8	50
Demand	15	20	30	35	$\sum$ 100

Sum of capacity = sum of demand.

Can be modeled as a linear program and solved using Excel Solver.
There are simple heuristics that can be used to approximate the solution e.g., **column minima method**.

Transportation problem: Linear program

Sets and parameters

I	Set of **built** locations (index i, $\lvert I\rvert = m$)
J	Set of customers (index j, $\lvert V\rvert = n$)
c_{ij}	transportation cost **per unit** from location i to customer j
s_i	Supply of location i
d_j	Demand of customer j

Decision variables

x_{ij}	how many units are transported from location i to customer j.

$$\min \sum_{i\in I}\sum_{j\in J} c_{ij}x_{ij}$$

$$\text{s.t.} \sum_{i\in I} x_{ij} = d_j \qquad \forall j \in J$$

$$\sum_{j\in J} x_{ij} \leq s_i \qquad \forall i \in I$$

$$x_{ij} \geq 0 \qquad \forall i \in I, j \in J$$

Heuristic: Column minima method

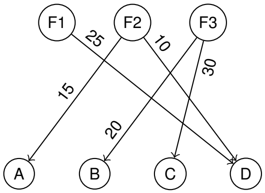
- In each iteration:
  - Choose the column that is furthest to the left and has not yet been crossed out.
  - Choose the smallest cost value and maximize the transportation amount.
  - If the supply of a location is completely allocated, cross out the line.
  - If the demand of a location is completely fulfilled, cross out the column.

Heuristic: does not necessarily find the optimal solution!

Example: Column minima method

i,j	A	B	C	D	s_i
1	10	5	6	11 25	25
2	1 15	2	7	4 10	25 10
3	9	1 20	4 30	8	50 30
d_j	15	20	30	35	100

Solution



Costs: $11 \cdot 25 + 1 \cdot 15 + 4 \cdot 10 + 1 \cdot 20 + 4 \cdot 30 = 470$

Technology and Supply Chain Trends

- IoT, digitalization (math. modeling of the supply chain)
- Rethink outsourcing.
- Use of analytics/AI, Big Data
- Sustainability, Circular Supply Chains

Examples (1)

Logistics 4.0

- **Agilox**: `https://www.agilox.net/de/agilox-igv`
- **Lufthansa Technik (AutoStore)**: `https://www.lufthansa-technik.com/warehouse`

UPS : Chatbot, MyChoice, Orion (Transportation planning), Edge (internal operations) `https://www.forbes.com/sites/bernardmarr/2018/06/15/the-brilliant-ways-ups-uses-artificial-intelligence-machine-learning-and-big-data`

Examples (2)

7LYTIX: AI, e.g., to improve forecasting `https://www.7lytix.com/`
"Apr 2025: KEBA Group acquires AI pioneer"

prewave: AI to forecast supply chain events/risks. `https://www.prewave.com`

RISC (Big) Data analytics in production and logistics
`https://www.risc-software.at/schwerpunkt/industrial-ai-and-simulation/`

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Summary

- Using the Center of Gravity method or solving the Steiner-Weber problem, the best coordinates for a new location can be calculated.
- The p-median problem is solved when a small set of p locations should be chosen out of a larger set of possible locations.
- The transportation problem is solved to minimize delivery costs between already built locations and customers.
- Supply chain trends include digitalization, use of AI, sustainability.