New Optimization Methods for Strategic Supply Chain Design

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GOR Working Group Supply Chain Management
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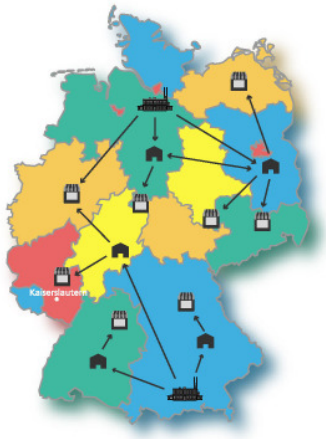
Outline

- Supply chain design: typical decisions and models
- New supply chain design model
  - formulation as MILP
  - relation to existing models
  - heuristic approach
- Numerical results
- Conclusions & outlook



Supply Chain Design

Optimization of the existing supply chain structure

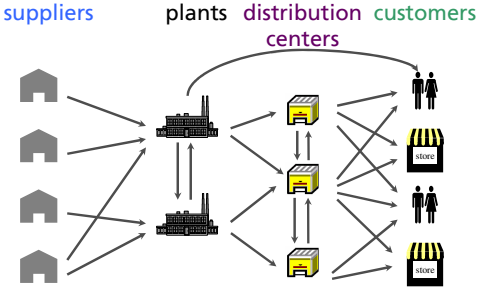
- Adapting the supply chain structure and processes to business changes
- Effects of changes in capacities and product ranges of individual facilities

Supply chain (re)design

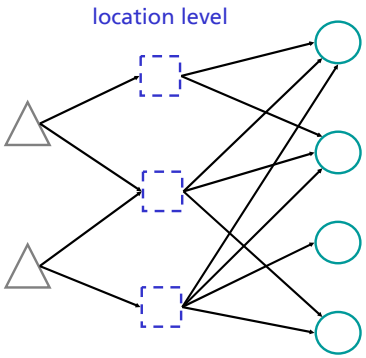
- Design supply chain to cope with long-term market changes (e.g. additional target markets)
- Effects of new distribution strategies, such as consolidation of warehouses
- Relocation of business processes (e.g. product lines) to different locations
- Consolidation of different supply chain networks as a result of a merger

Strategic decisions

- Procurement: selecting among suppliers and determining materials needed
- Production: determining product ranges and production levels
- Location: number, geographic location and capacities of new/existing facilities
- Distribution: selecting transportation channels for shipping products between facilities
- Customer allocation: allocation of customers to service locations (e.g. direct delivery from plants to customers)



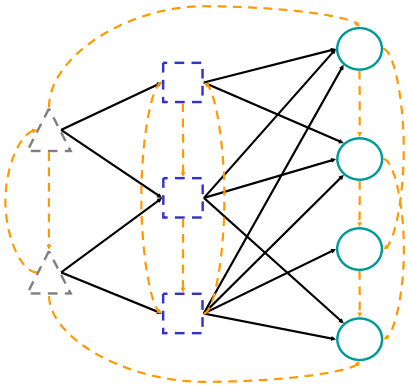
Typical supply chain models found in the literature



typical network structure

- **specific network:** categorization of facilities into levels, usually maximum 3 levels
- product **flow** from **one level to the next** (e.g. plants → DCs → customers)
- strategic decisions focus on **facility location** and allocation
- facility **location restricted** to one or two levels (e.g. locate new DCs; locate new plants and DCs)
- demand occurs in the lowest level of the network

Practical needs

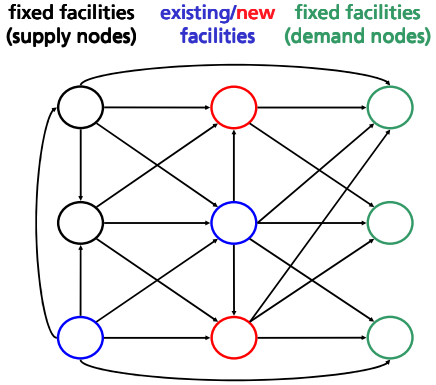


general network structure

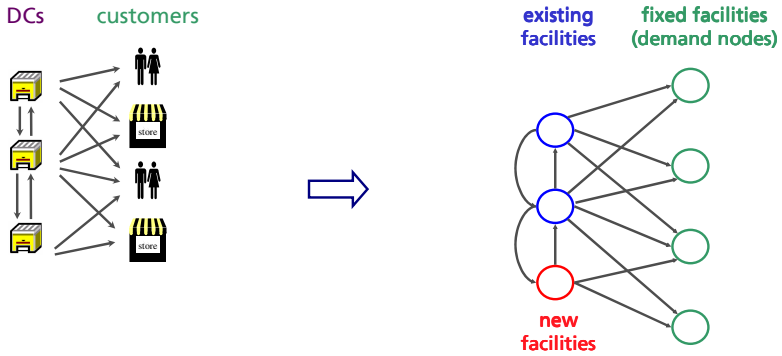
- **general network:** no echelon structure required, no restriction on the type of facilities
- product **flow** allowed **between any type** of facility and in any direction (e.g. inter-facility transportation)
- additional strategic planning possible, e.g. **production, procurement**
- no restrictions on the type of facilities to **open/close**
- demand can occur in any type of facility

New model for supply chain design

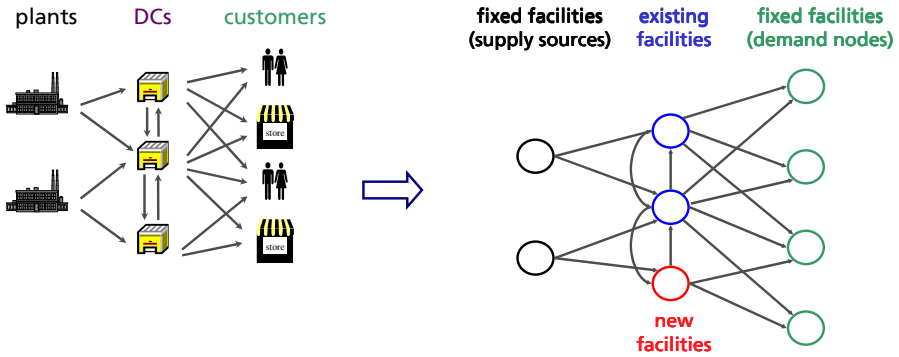
- fixed facility, e.g. plant
- fixed facility, e.g. customer
- existing facility
- new facility
- commodity flow



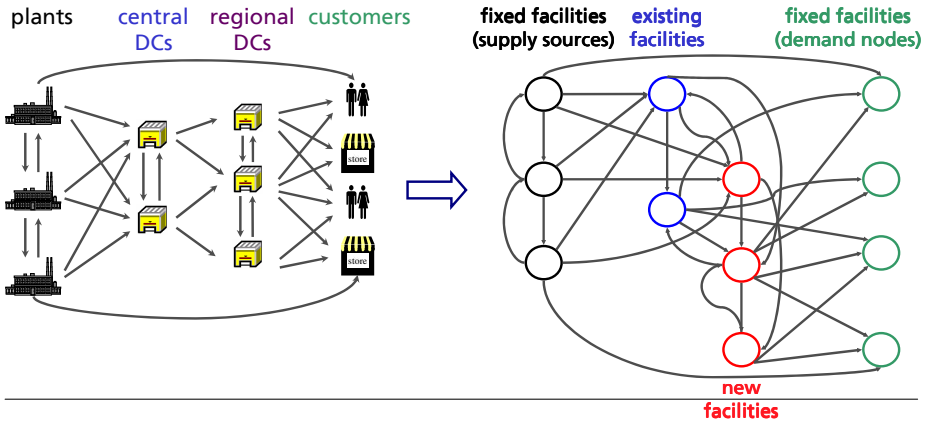
Example: simple structure



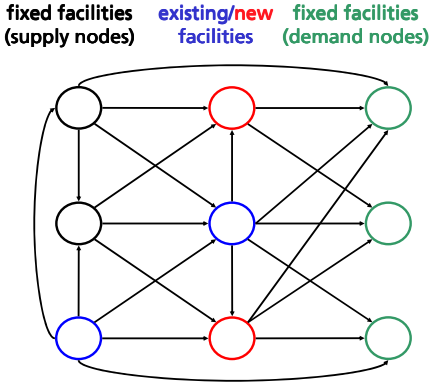
Example: 2-level structure



Example: 3-level structure



New model for supply chain design



- General supply chain structure
  - unrestricted number, combination of echelons
  - shipping lanes in any direction
- New / existing facilities anywhere in network
- Strategic decisions
  - *dynamic location planning*
  - *operational activities*
  - *investments*

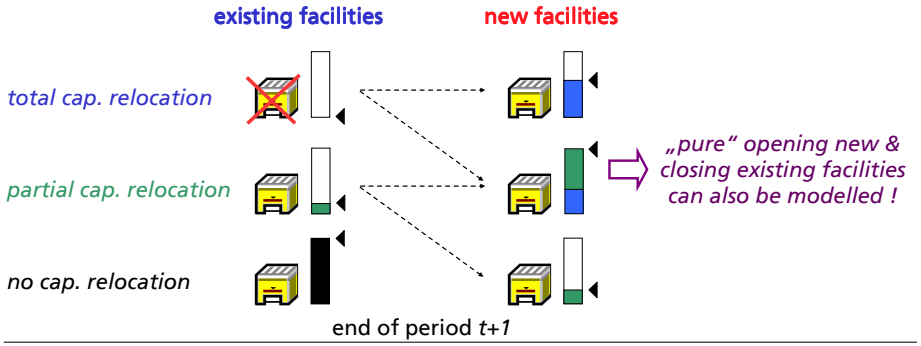
Dynamic location planning: motivation

- Long-term project
- Large investment capital → financial strain on the company
- Robust facilities → cope with current and future system conditions
- Time-consuming project → new infrastructure, new equipment, employee training, …
- Gradual setup of new facilities and phase-out of existing facilities
- Coordination of all operational aspects → no disruption of supply chain activities
- Practical situation: relocation of production facilities, new target markets

➡ gradual location / relocation of facilities through capacity shifts

Dynamic locational decisions

Modelling through **capacity transfers** from existing to new facilities



Operational decisions

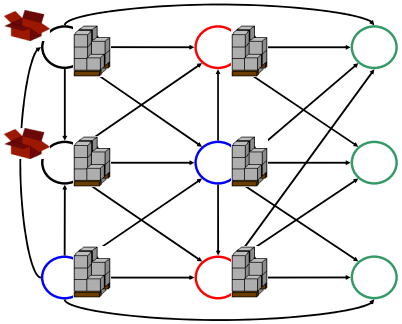
fixed facilities (supply nodes) | existing/new facilities | fixed facilities (demand nodes)

Supply → amount of products supplied or produced per period

Distribution → flow of products in shipping lanes / period

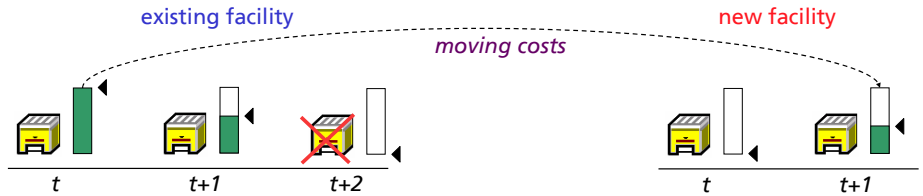
Inventory → stock level in each facility / period & product

non-zero stocks at begin of horizon



Investment decisions

Budget for opening new facilities, moving capacity and closing existing facilities / period



fixed closing costs ↓ *no shutdown at the end of last period*

fixed opening costs ↓ *first opening opportunity in period 2*

Non-invested budget in a period earns interest rate and can be used later

Large scale mixed integer linear programming model

Objective function — **Minimize total costs**

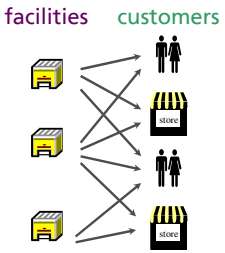
- var. external supply, transportation, inventory holding costs
- fixed facility operating costs

Constraints

- flow conservation per facility, product, period (incl. demand satisfaction)
- feasible capacity transfers from existing to new facilities
- product flows below capacity limits per facility, period
- min. throughput per facility, period
- open / close a facility at most once
- feasible investments for opening & closing facilities and capacity transfers per period

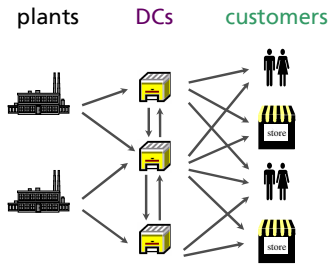
Relation to known models

- Generalization of many (dynamic) facility location models with individual features (Melo et al., C&OR 33, 2006)
- Classical models: no gradual capacity relocation → „pure“ opening new / closing existing facilities
- NP-hard problem: reduction to dynamic formulation of Van Roy & Erlenkotter (MS 28, 1982)
  - simple network structure
  - single commodity
  - no capacities
  - no budget restrictions
  - location & allocation



Example

- 10 periods
- 10 products
- 5 plants
- 50 customers
- 10 existing distribution centers
- 20 potential sites for new DCs



→ 10 270 constraints

→ 732 810 non-negative variables

→ 270 binary variables — status of facilities

Problem characteristics

Two types of decision variables:

- non-negative continuous (capacity transfers, transportation, inventory, investments)
- binary → status change of a facility in a period = 1

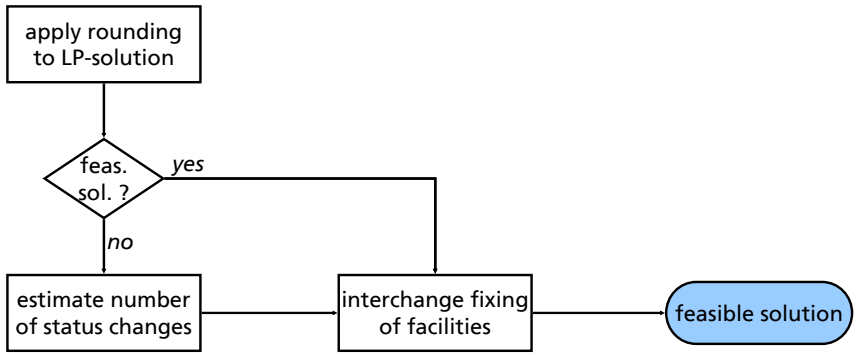
	1	2	3	4	5
	periods				
new fac.	×0	×0	×0	×0	×0
	×0	×0	✓1	✓0	✓0
ex. fac.	✓0	✓0	✓1	×0	×0

for given status matrix, resulting problem is an LP !

0 no status change
1 status change

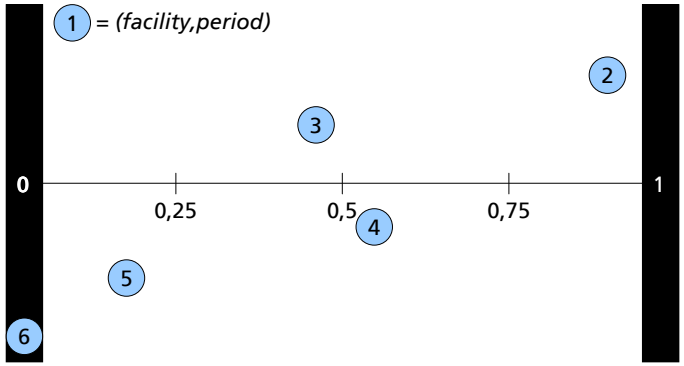
✓ open
× closed

Heuristic approach



Heuristic approach – Step 1

a) Solve LP-relaxation by taking facility status variables in [0,1]



Working Group SCM, 28 Oct. 2005

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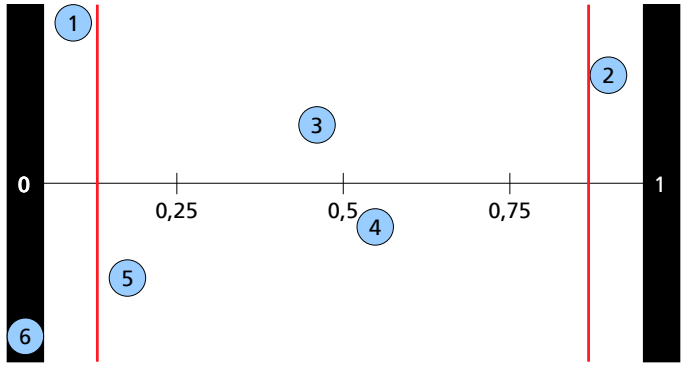

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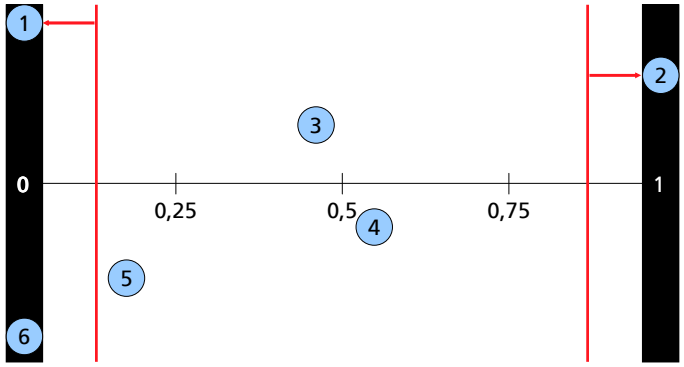
Heuristic approach – Step 1

b) Fix facility status variables with very small or large fractional values to 0 resp. 1



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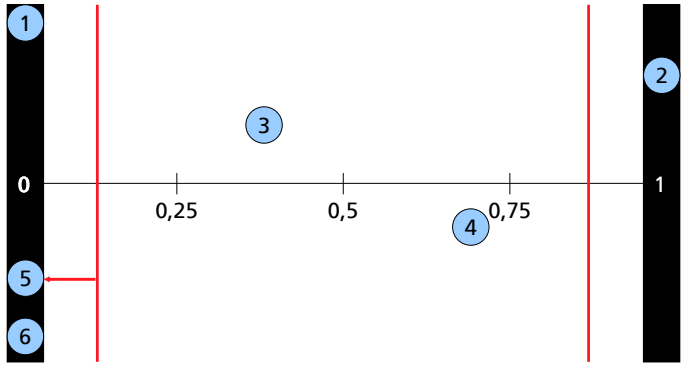
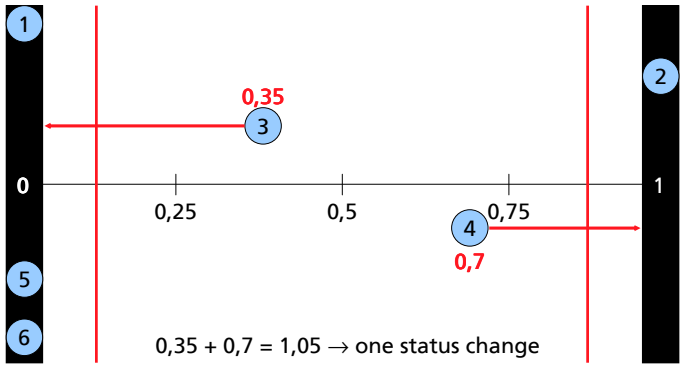
Heuristic approach – Step 1

c) Solve LP-subproblem and apply rounding procedure



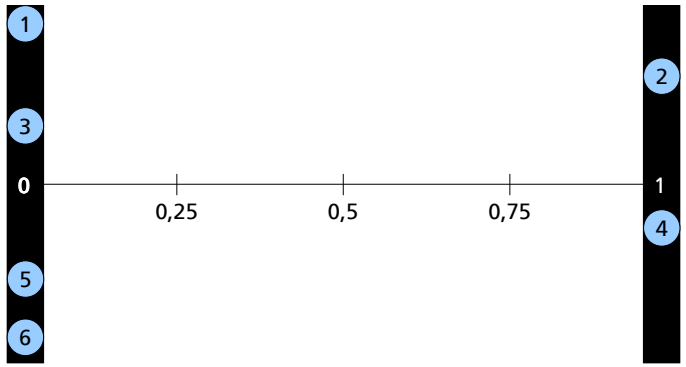
Heuristic approach – Step 1

d) Fix remaining facility status variables at 0 / 1



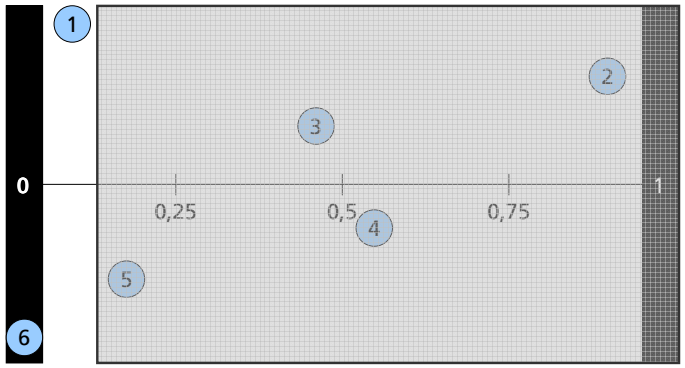
Heuristic approach – Step 1

e) If solution is not feasible then go to next step



Heuristic approach – Step 2

Idea: use LP-relaxation to identify „attractive“ facilities for a status change



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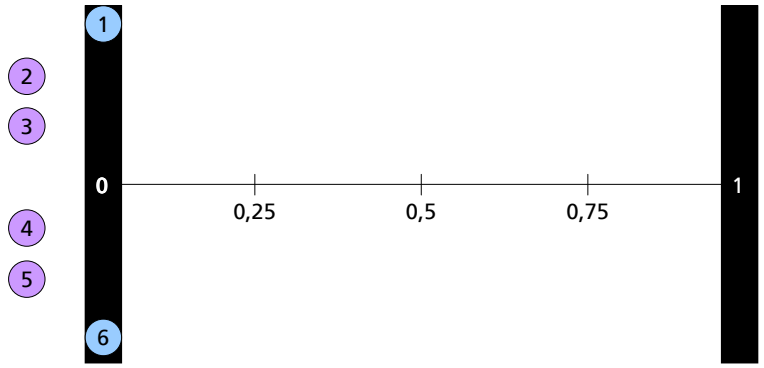
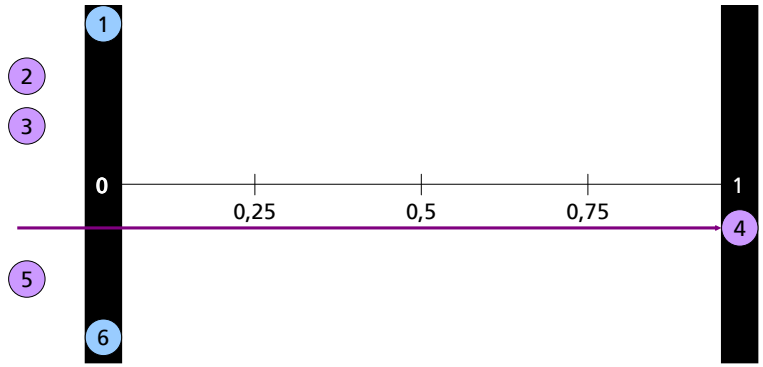


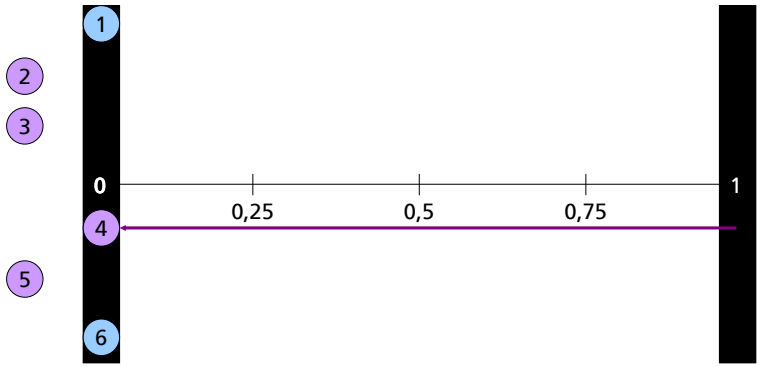
Heuristic approach – Step 2

a) Fix randomly chosen status variable to 1, solve LP-subproblem



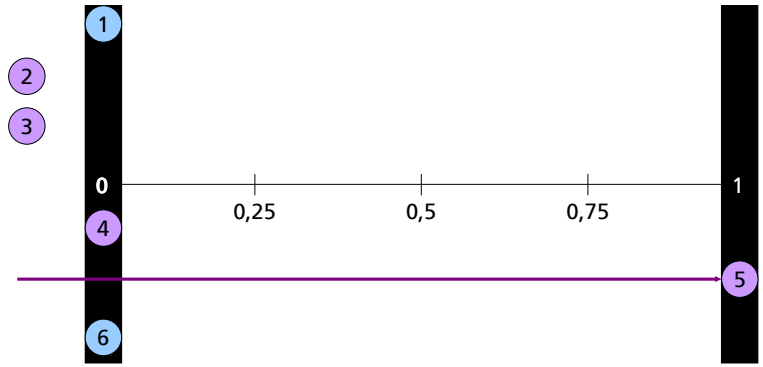
Heuristic approach – Step 2

a) Undo fixing when LP-subproblem is infeasible and fix to 0



Heuristic approach – Step 2

b) Repeat successively for all „attractive“ facilities

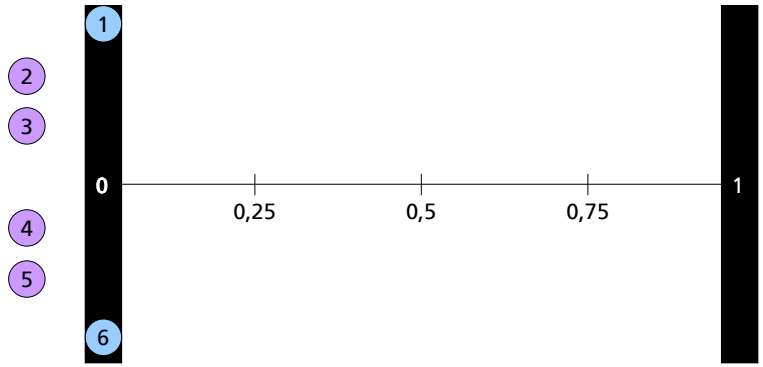


Heuristic approach – Step 2

c) If solution is not feasible then estimate *total number of status changes*

Heuristic approach – Step 2

d) Select randomly variables for status change using estimated number



Heuristic approach – Step 2

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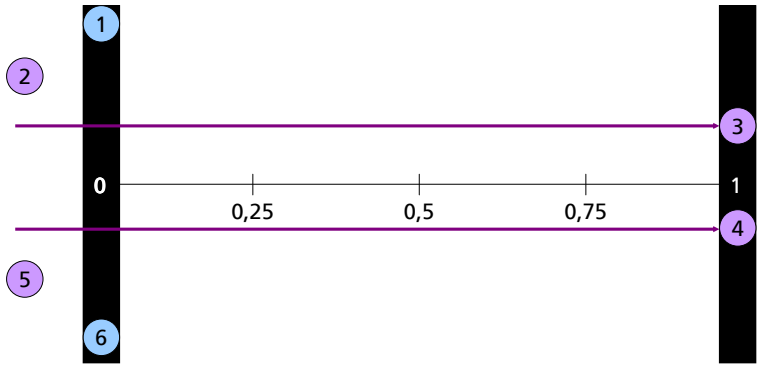
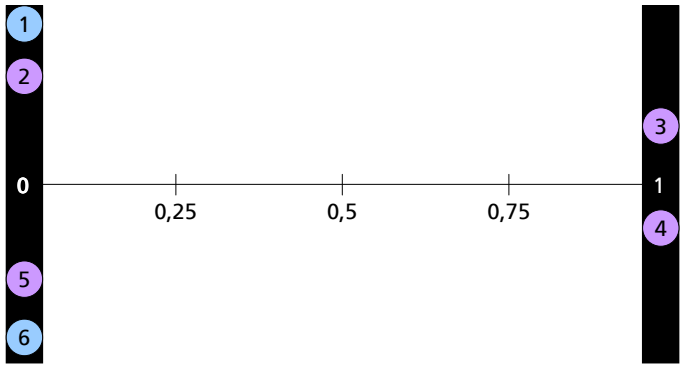


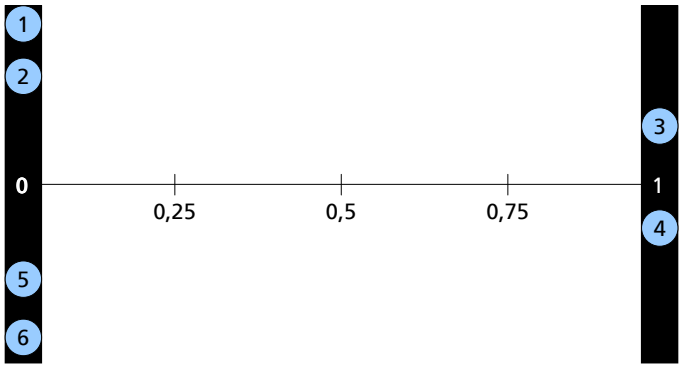
Heuristic approach – Step 2

e) If solution is not feasible then go to next step



Heuristic approach – Step 3

a) Interchange facility fixing: *involving 2 facilities …*



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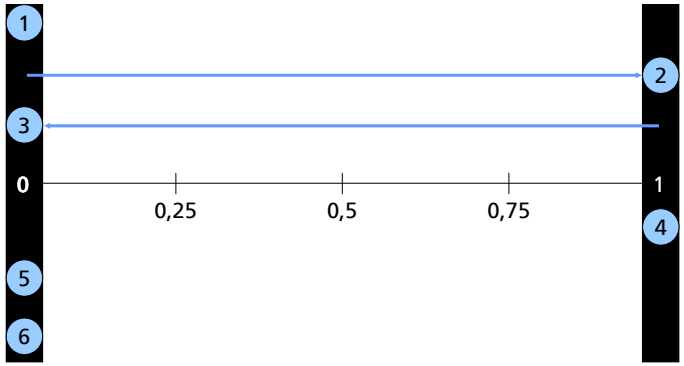

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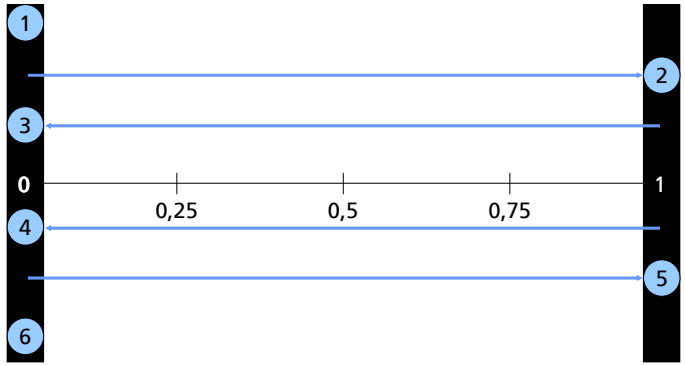
Heuristic approach – Step 3

b) Interchange facility fixing: *involving 4 facilities …*



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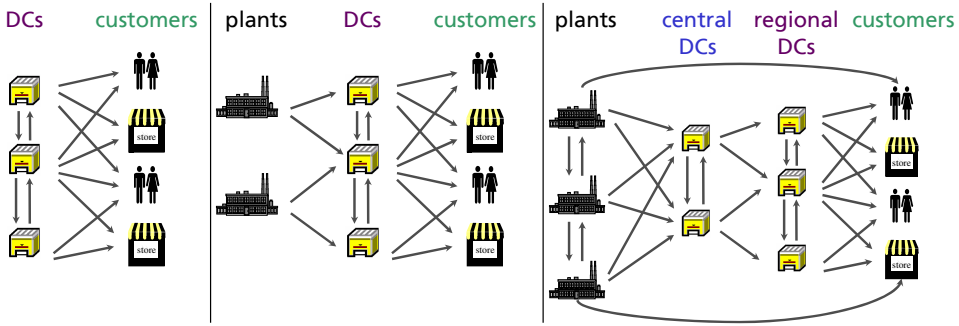
Numerical tests



periods: 3, 4, 5, 6
products: 5, 10, 15

plants: 5
customers: 50, 75, 100, 150

DCs: 30 - 32 location level

up to 60 000 cont. var.
180 bin. var.
5 200 const.

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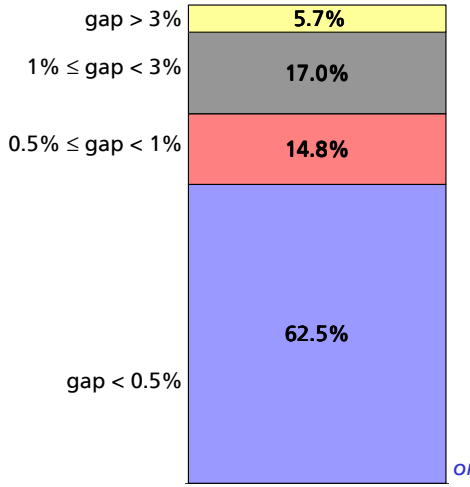
Solution quality*



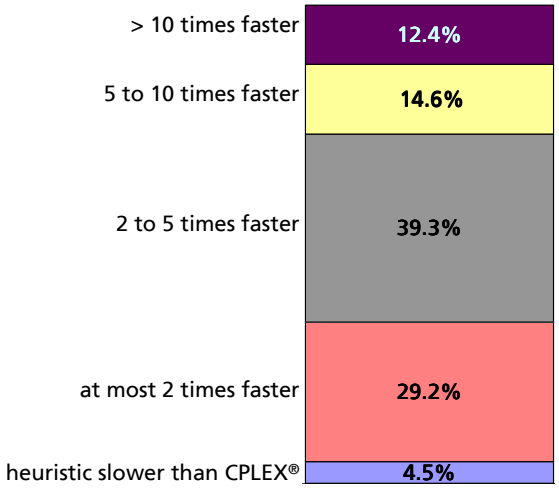
	gap
average	*0.8 %*
median	*0.3 %*
min.	*0.0 %*
max.	*10.3 %*

$$= \frac{heur - opt}{opt} \times 100\%$$

only 1 problem could not be solved …

* 90 test problems solved with CPLEX® 7.5 to optimality
* heuristic coded in C++

Running time performance



Conclusions & outlook

- LP-based heuristic approach
  - very good quality solutions
  - very fast
  - no guarantee of reaching feasibility
- Work in progress
  - refinement of heuristic (feasibility, time)
  - extension to cap. Expansion / reduction situations
  - consideration of international aspects, e.g. duties, tax rates

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