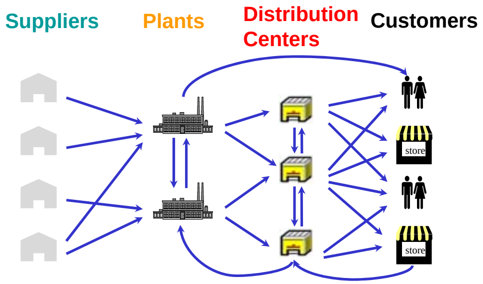
Karlsruhe Institute of Technology

Location Problems in Supply Chain Management

Stefan Nickel

Institute for Operations Research
Karlsruhe Institute of Technology (KIT)



Location Problems in SCM

Contents

- A Supply Chain Design Problem with facility location, production and transportation activities
- The real problem: Multi-Period Relocation Problems
- Strategic Supply Chain Model from Practice
- Heuristic Solution Procedures
- (Applications and Software)

Location Problems in SCM

Contents

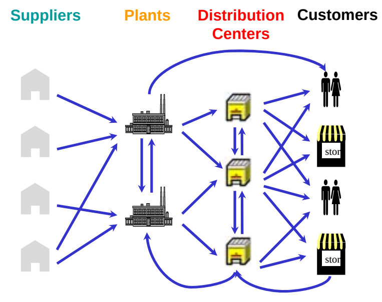
A Supply Chain Design Problem with facility location, production and transportation activities

- Strategic planning
- MIP formulation
- Numerical results

Location Problems in SCM

Strategic Planning of Supply Chains

- **procurement**:
  set of suppliers to select &
  amount of raw materials to acquire?
- **production**:
  which products to manufacture,
  where and in which amount?
- **facility location**:
  number, location, capacity of new service facilities to open?
  Number, location of existing service facilities to keep?
- **transportation**:
  which transportation channels to use
  to ship products between facilities?
- **customer allocation**:
  which customers to serve by which facility?



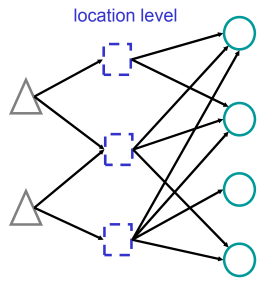
Characteristics of Strategic Planning

- Highly aggregated data
- High uncertainty in data or even no data
- Decisions involve the upper management
- Specialized and well trained users
- Running time of algorithms is non-critical
- No classical fixed costs
- Operational decisions (like „make or buy“) should not be modeled

Facility Location Models in SCM

Typical features found in the literature

- Specific network: categorization of facilities into levels, usually maximum 3 levels
- product flow from one level to the next (e.g. plants $\rightarrow$ DCs $\rightarrow$ 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

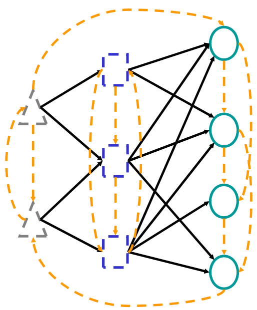


typical network structure

Facility Location Models in SCM

Practical needs

- 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-depot transportation, recycling)
- 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

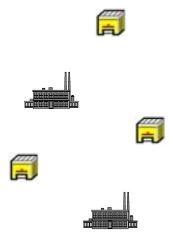


general network structure

Supply Chain Networks

Practical needs

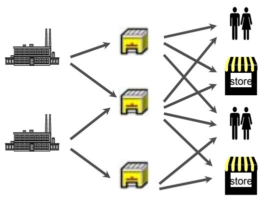
- Different types of facilities



Supply Chain Networks

Practical needs

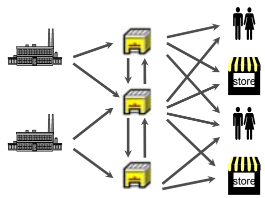
- Different types of facilities
- Multiple facility layers



Supply Chain Networks

Practical needs

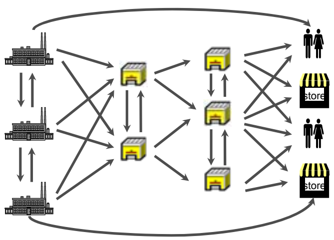
- Different types of facilities
- Multiple facility layers
- Flow between facilities in the same layer



Supply Chain Networks

Practical needs

- Different types of facilities
- Multiple facility layers
- Flow between facilities in the same layer
- Direct shipments



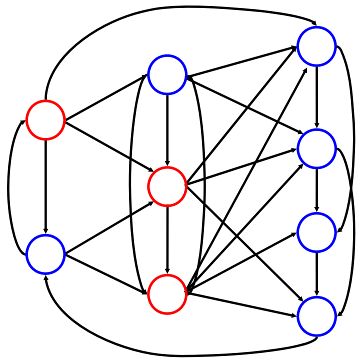
Location Problems in SCM

Contents

A Supply Chain Design Problem with facility location, production and transportation activities

- Strategic planning
- MIP formulation
- Numerical results

A General Supply Chain Design Model



non-selectable facility

selectable facility

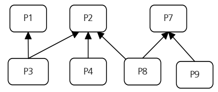
decision: operate a selectable facility (y/n)?

selectable facilities	fixed costs: closing	fixed costs: opening
existing	X	-
potential	-	X

A General Supply Chain Design Model

Activities | **Decision Variables** (product p, facility i)

- procurement — $b_{i,p}$ ≡ amount of p bought by facility i
- production — $h_{i,p}$ ≡ amount of p produced by facility i



← modelling production processes

- transportation — $v_{i,j,p}$ ≡ amount of p shipped from facility i to facility j
- facility operation — $\delta_i \equiv \begin{cases} 1 & \text{if selectable facility } i \text{ operates} \\ 0 & \text{otherwise} \end{cases}$
- capacity expansion — x_r, y_r ≡ amount of additional production /handling resource r used
- unsatisfied demand — $z_{i,p}$ ≡ amount of p not delivered to facility i

Capacity Modelling

resource consumption in

- production, e.g. equipment, number of working shifts $(\mu_{i,r,p})$
- handling of goods, e.g. pallet loader for incoming/outgoing goods in a facility $(\vec{\lambda}_{i,r,p}, \overleftarrow{\lambda}_{i,r,p})$

resource – facility combination

- one – to – many → same resource used in several facilities
- one – to – one → same resource used by all products in a facility
- many – to – one → different resources used by several products in a facility

resources have limited availability

resource extension, e.g. through overtime work
→ additional costs charged

A Mixed Integer Program

Objective function

procurement costs ↓ production costs ↓

$$\min \sum_{i\in I}\sum_{p\in P} BC_{i,p}\, b_{i,p} + \sum_{i\in I}\sum_{p\in P} HC_{i,p}\, h_{i,p}$$
$$+ \sum_{i\in I}\sum_{\substack{j\in I,\\ j\neq i}}\sum_{p\in P} TC_{i,j,p}\, v_{i,j,p}$$
$$+ \sum_{r\in R^p} EPC_r\, x_r + \sum_{r\in R^h} EHC_r\, y_r$$
$$+ \sum_{i\in I}\sum_{p\in P} PDC_{i,p}\, z_{i,p}$$
$$+ \sum_{i\in S} OC_i\, \delta_i + \sum_{i\in S} CC_i\,(1-\delta_i)$$

← transportation costs

capacity expansion costs →

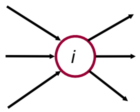
← penalty demand costs

↑ opening costs new facilities ↑ closing costs existing facilities

A Mixed Integer Program

Constraints I

- general flow conservation for every product *p*, in every facility *i*



"outbound" flow: transport out of *i*; production of other products; demand; unsatisfied demand

$$b_{i,p} + \sum_{\substack{j\in I\\ j\neq i}} v_{j,i,p} + h_{i,p} = \sum_{\substack{k\in I\\ k\neq i}} v_{i,k,p} + \sum_{q\in P} a_{i,p,q} h_{i,q} + d_{i,p} - z_{i,p}$$

"inbound" flow: procurement; transport into *i*; production of *p*

A Mixed Integer Program

Constraints II

- resource consumption and capacity expansion

production resources:

$$\sum_{i\in I}\sum_{p\in P} \mu_{i,r,p} h_{i,p} \le PK_r + x_r, \qquad r\in R^p$$

$$0 \le x_r \le \overline{PK}_r, \qquad r\in R^p$$

(available capacity)

handling resources:

$$\sum_{i\in I}\sum_{\substack{j\in I,\\ j\neq i}}\sum_{p\in P} \left(\overleftarrow{\lambda}_{i,r,p} + \vec{\lambda}_{j,r,p}\right) v_{i,j,p} + \sum_{i\in I}\sum_{p\in P} \vec{\lambda}_{i,r,p} b_{i,p} \le HK_r + y_r, \qquad r\in R^h$$

$$0 \le y_r \le \overline{HK}_r, \qquad r\in R^h$$

A Mixed Integer Program

Constraints III

- activities in **selectable facilities**

$b_{i,p} \le M_{i,p}\delta_i,$	$i\in S, p\in P$	procurement
$h_{i,p} \le M_{i,p}\delta_i,$	$i\in S, p\in P$	production
$v_{i,j,p} \le M_{i,j,p}\delta_i,$	$i\in S, j\in I\ (j\neq i), p\in P$	transportation ***out*** of a selectable facility *i*
$v_{i,j,p} \le M_{i,j,p}\delta_j,$	$i\in I\setminus S, j\in S, p\in P$	transportation ***into*** a selectable facility *j*

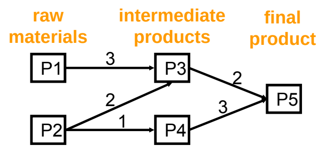
(M: upper bound depending on material requirements & resource availability)

- integrality and non-negativity conditions

$$b_{i,p}\ge 0, h_{i,p}\ge 0, 0\le z_{i,p}\le d_{i,p} \qquad i\in I, p\in P$$
$$v_{i,j,p}\ge 0 \qquad i,j\in I, (i\neq j), p\in P$$
$$\delta_i\in\{0,1\} \qquad i\in S$$

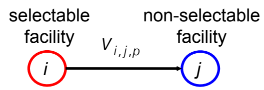
Choosing suitable upper bounds *M*

Taking material requirements into account



$MD_p \equiv$ max. amount of product *p* required in the network

Taking resource availability in each **selectable facility** into account



$$v_{i,j,p} \le M_{i,j,p}\,\delta_i$$

$$M_{i,j,p} = \min\left\{MD_p, \min_r \frac{\text{capacity } r \text{ in } i}{\text{consumption}}, \min_r \frac{\text{capacity } r \text{ in } j}{\text{consumption}}\right\}$$

Location Problems in Supply Chain Management

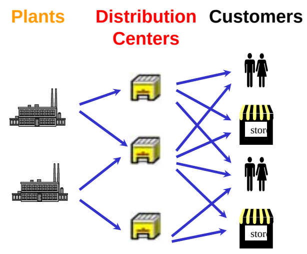
Contents

A Supply Chain Design Problem with facility location, production and transportation activities

- Strategic planning
- MIP formulation
- Numerical results

Numerical Tests

- 72 test problems randomly generated
- structure of distribution network
  - 50 – 200 customers
  - 5, 10, 15 product types
  - one-level: 30 selectable DCs (10 existing + 20 potential)
  - two-level: 5 plants, 30 selectable DCs (10 existing + 20 potential)
  - dense transportation network (70-80%)
  - all costs randomly generated (production, transportation, capacity expansion) (uniform dist.)
  - incapacitated & capacitated instances



Numerical Results

problem type		#var	#const	root LP gap(%)	CPU (sec.)	root feas. sol gap(%)	CPU (sec.)	#B&B nodes	total CPU (sec.)
uncap.	min.	2439.0	2542.0	0.0	0.0	0.0	0.0	0.0	2.0
	average	14088.3	14528.8	4.2	14.7	5.3	49.2	30.7	139.6
	max.	29345.0	30414.0	16.4	15.0	16.0	573.2	68.0	149.2
large cap.	min.	2598.0	2578.0	0.0	0.0	0.0	0.0	0.0	4.5
	average	13268.3	13430.4	8.4	54.4	2.0	279.8	207.2	3818.0
	max.	30909.0	31470.0	20.6	264.5	12.3	1546.3	1141.0	34030.0
medium cap.	min.	2598.0	2579.0	0.0	0.9	0.0	4.7	0.0	7.4
	average	13268.4	13430.7	12.6	40.1	3.7	226.0	1784.8	8187.2
	max.	30909.0	31471.0	44.2	196.5	31.6	1276.6	18578.0	59796.3

Problems modeled with ILOG Concert (C++ interface) and solved optimally with CPLEX® 7.5 in a Pentium III, 850 MHz, 1 GB RAM

Location Problems in SCM

Contents

- A Supply Chain Design Problem with facility location, production and transportation activities
- The real problem: Multi-Period Relocation Problems
- Strategic Supply Chain Model from Practice
- Heuristic Solution Procedures
- (Applications and Software)

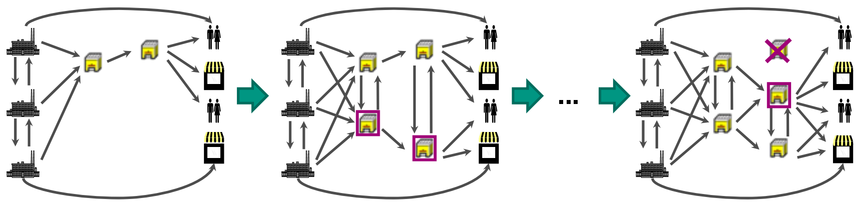
Supply Chain Networks

Practical needs

- Different types of facilities
- Multiple facility layers
- Flow between facilities in the same layer
- Direct shipments
- Network redesign

  → Multi-period process

Flexibility!



Dynamic relocation of facilities

Motivation

Melo, Nickel, Saldanha da Gama, 2006, COR

Facility location

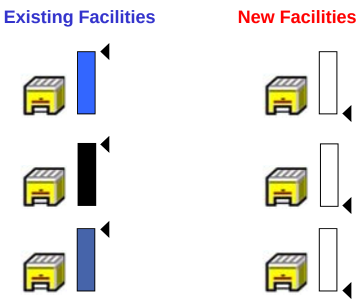
- Long-term project
- Robust facilities → cope with current and future system conditions
- Large investment capital → financial strain on the company
- Time-consuming activities → new infrastructure, equipment supply, employee training, …
- Gradual setup of new facilities and phase-out of existing facilities
- Coordination of all operational aspects → supply chain activities cannot be disrupted
- Practical situation: relocation of production facilities, new target markets

➡ gradual location / relocation of facilities through capacity shifts

Model features

Facility relocation through capacity shifts

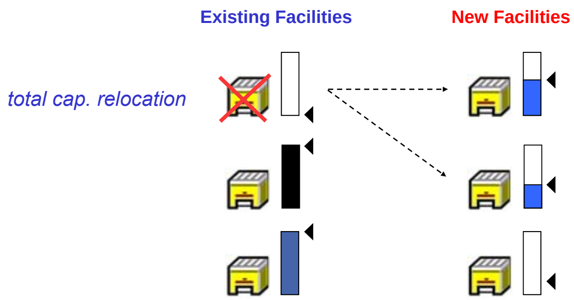
(Gradual) capacity transfers from existing to new facilities during the planning horizon



end of period *t*

Model features

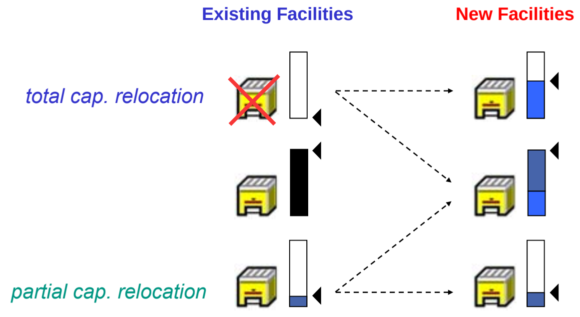
(Gradual) capacity transfers from existing to new facilities during the planning horizon



end of period *t+1*

Model features

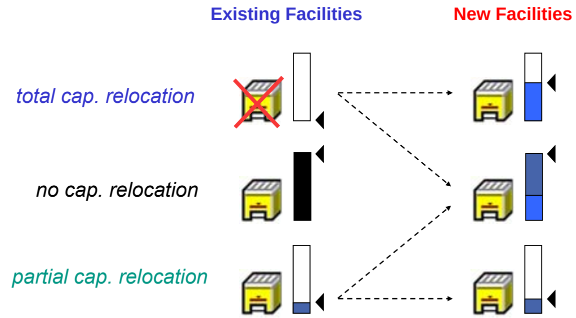
(Gradual) capacity transfers from existing to new facilities during the planning horizon



end of period *t+1*

Model features

(Gradual) capacity transfers from existing to new facilities during the planning horizon

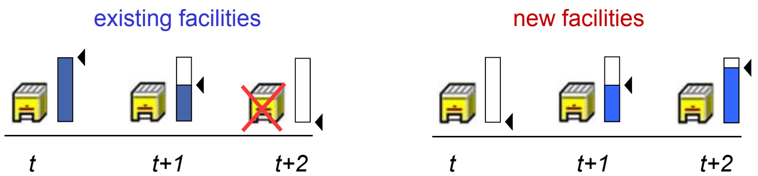


end of period *t+1*

Model features

Financial budget

Availability of investment capital in each period for opening new facilities, moving capacity and closing existing facilities



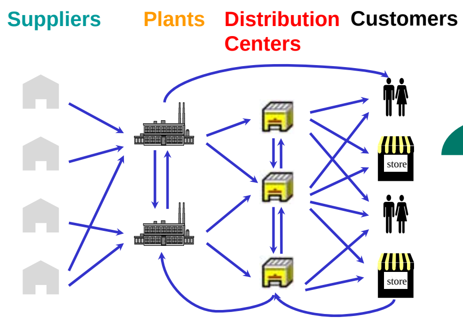
existing: *t*	*t+1*	*t+2*	new: *t*	*t+1*	*t+2*
	variable capacity moving costs	variable capacity moving costs, *fixed closing costs*	*fixed opening costs*	variable capacity moving costs	variable capacity moving costs

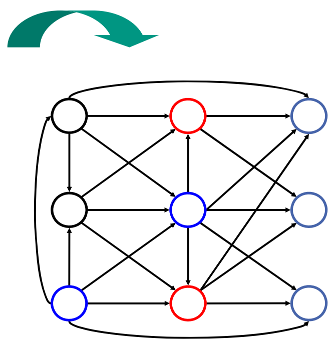
→ no shutdown at the end of last period

→ first operation period is 2

Model features

General Supply Chain Structure



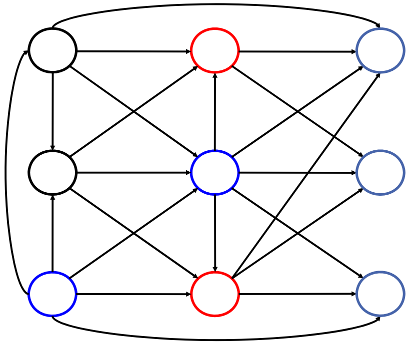


Model features

not restricted to an echelon structure

shipping lanes in any direction, e.g. inter-facility transportation, reverse logistics

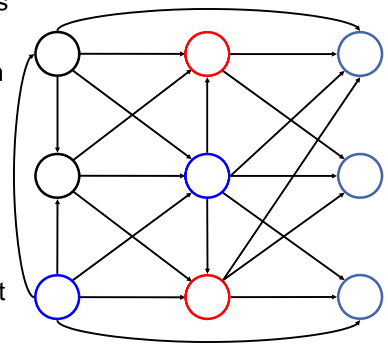
- fixed facility, e.g. plant
- fixed facility, e.g. customer
- existing facility
  - *capacity transfers*
- new facility
- commodity flow



Model features

Additional Aspects

- Available budget per period:
  use non-invested capital in previous periods subject to interest rate
- External supply of products through procurement / production (supply nodes)
- Facilities with limited capacity
- Min. throughput at facilities
- Inventory opportunities for goods in each period (availability of stocks at the beginning of the planning horizon)



Dynamic relocation of facilities

Decisions

- **Supply**
  Amount of product *p* purchased by facility *i* in period *t* ?
- **Transportation**
  Amount of product *p* shipped from facility *i* to facility *j* in period *t* ?
- **Inventory**
  Amount of product *p* held in stock in facility *i* at the end of period *t* ?
- **Facility operation**
  Should facility *i* be operated in period *t* ?
- **Relocation**
  Amount of capacity to shift from the existing facility *i* to a new facility *j* at the beginning of period *t* ?
- **Capital investment**
  Capital available at the end of period *t* ?

Dynamic relocation of facilities

Model

- **Objective function**
  Minimize total costs
  - external supply, transportation, inventory holding costs
  - fixed facility operating costs
- **Constraints**
  - general conservation of flow per facility, product, period
  - feasible capacity transfers from existing to new facilities
  - capacity limits per facility, period
  - min. throughput per facility, period
  - open / close a facility at most once during planning horizon
  - budget limitations for investments on opening & closing facilities and capacity shifts per period
- Large MIP model
- NP-hard: reduction to dynamic model of Van Roy & Erlenkotter (MS, 1982)

Location Problems in SCM

Contents

- A Supply Chain Design Problem with facility location, production and transportation activities
- The real problem: Multi-Period Relocation Problems
- Strategic Supply Chain Model from Practice
- Heuristic Solution Procedures
- (Applications and Software)

Strategic Supply Chain Model from Practice

The **facilities modeled** in the supply chain do not necessarily have to be part of the **own organization**. E.g. external supplier.

Notation

- L Set of all facilities
- S Set of all selectable facilities
- S^o Set of all **selectable** facilities, which could be opened
- S^c Set of all **selectable** facilities, which could be closed

$\Rightarrow S = S^o \cup S^c$.

$\mathcal{P} = \{1, \dots, P\}$ Set of all products

$\mathcal{T} = \{1, \dots, T\}$ Set of all time periods

Strategic Supply Chain Model from Practice

Location decisions

Open

$$\ell \in S^o, t \in \mathcal{T} \qquad y_\ell^t := \begin{cases} 1 & \text{if facility } \ell \text{ is opened at the beginning of period } t \\ 0 & \text{otherwise} \end{cases}$$

Close

$$\ell \in S^c, t \in \mathcal{T} \setminus \{T\} \qquad y_\ell^t := \begin{cases} 1 & \text{if facility } \ell \text{ is closed at the end of period } t \\ 0 & \text{otherwise} \end{cases}$$

$$\ell \in S^c \qquad y_\ell^T := \begin{cases} 1 & \text{if facility } \ell \text{ is not closed} \\ 0 & \text{otherwise} \end{cases}$$

OC^t_ℓ Opening Costs for the facility $\ell \in S^o$ at the beginning of period t and for its operation for the rest of the planning period

CC^t_ℓ Costs for closure of the facility $\ell \in S^c$ at the end of period t and their operation until then.

Strategic Supply Chain Model from Practice

Demand

- Facilities can have demand for products.
- Forecast future demands.
- If the forecasts are not exact enough, then consider the problem **several times** for different scenarios of demand trends
  - pessimistic (worst-case)
  - normal (average-case)
  - optimistic
  - ...
- Notation

  $D^t_{\ell,p}$ Demand in quantity units for product p at facility ℓ in period t.

Strategic Supply Chain Model from Practice

Satisfaction of customer demands

It may be that the demand can/shall not be (completely) satisfied.

Example:

- Costs for the satisfaction of demand is too high (compared to profit)
- Supply within the given service time is not possible, or just with very high efforts
- Capacities are not sufficient

Unsatisfied demand incurs penalty costs.

However, they are difficult to quantify.

Possibility: lost profits, service level which has to be satisfied

$z^{t}_{\ell,p}$ — Number of quantity units of demand at facility ℓ for product p in period t, which were not delivered.

$PDC^{t}_{\ell,p}$ — Penalty costs per quantity unit of product p, which were not delivered to facility ℓ in period t to satisfy the demand.

Strategic Supply Chain Model from Practice

Procurement

Facilities can buy products from „external“, i.e. from **external suppliers**.

Example:

- **raw material** or **semi-finished goods**, which cannot be produced at their own facilities
- **products**, that are cheaper to buy than to produce them (Out-Sourcing)

Notation

$b^{t}_{\ell,p}$ — Amount of product p, which is procured at facility ℓ in period t.

$BC^{t}_{\ell,p}$ — Costs for procurement of one unit of product p at facility ℓ in period t.

Strategic Supply Chain Model from Practice

Production

Manufacturing of finished goods from different inputs.

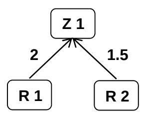
Example:

- „classical“ manufacturing of finished goods in factories from raw material and intermediate goods
- packaging or picking products in distribution centers. E.g. drill machine from factory A with boring head from factory B packed together.

Manufacturing processes are specified by bills of materials.

Example:

Intermediate product **Z1** is manufactured by raw material **R1** and **R2.** The numbers on the arcs indicate the related material consumption factors. The production of one unit of **Z1** needs ***2*** and ***1.5*** units of raw materials **Z1** and **Z2**, respectively



Strategic Supply Chain Model from Practice

Simplify multi-stage lists of material to single-stage ones.

Notation

$a_{\ell,p,q}$ — Number of units of product q, needed to manufacture one unit of product p in facility ℓ.

$h^{t}_{\ell,p}$ — Amount of product p, produced in facility ℓ in period t.

$HC^{t}_{\ell,p}$ — Costs for manufacturing one unit of product p in facility ℓ in period t. Includes costs for material, machine utilization, ….

Strategic Supply Chain Model from Practice

Storage

Products (raw material, intermediate products, finished goods) can be stored in facilities from **one period to the next**.

Notation

$inv^t_{\ell,p}$	Amount of product p stored at facility ℓ in period t.
$IC^t_{\ell,p}$	Costs for storing one unit of product p at facility ℓ in period t. Include costs for inventory, stock ground, …

Strategic Supply Chain Model from Practice

Distribution

Transportation links **between all facilities** possible.

Notation

$x^t_{\ell,\ell',p}$	Amount of product p transported from facility ℓ to ℓ' in period t.
$TC^t_{\ell,\ell',p}$	Transportation costs for one unit of product p from facility ℓ to ℓ' in period t.

- The transportation costs depend on the **distance,** but also on the **product** and the **means of transportation**.
- Include often **costs** for goods issue (e.g. order picking, shipment) at the starting facility and for incoming goods (warehousing) at the destination facility.
- Sometimes **costs** for storage (within a period) at the starting location, too.

Strategic Supply Chain Model from Practice

Capacities

Displayed via resources.

Example:

- machine, stockyard
- storage, order picking system
- staff, shift

Resources characterized by

- Base capacity (e.g. production capacity of a machine, maximal throughput of the picking system per period).
- Consumption factor states for each product the consumption of resources in resource units per quantity unit of a product.
- Expansible capacity of the resource (e.g. overtime, leasable storage or production capacity).
- Penalty costs per unit, that extend (overload) the base capacity.

Strategic Supply Chain Model from Practice

Relations between facilities and resources

- **one – to – many**
  - The same resource can be used on several facilities.
  - Example: executive producer, which is responsible for several production lines
- **one – to – one**
  - The same resource is used by all products of one facility.
  - Example: flexible configurable machine
- **many – to – one**
  - Several resources attached in the same facility.
  - Example: facilities correspond to production lines and resources to executive producers

Consider resources for

- production and
- incoming goods and goods issue (handling)

Strategic Supply Chain Model from Practice

Notation

- R^p Set of production resources
- R^h Set of handling resources
- $\mu_{\ell,r,p}$ Consumption factor of production resource $r \in R^p$ per unit of product p at facility ℓ.
- $\lambda^i_{\ell,r,p}$, $\lambda^o_{\ell,r,p}$ Consumption factor of production resource $r \in R^h$ per unit of product p at goods receipt respectively issue at facility ℓ.
- v^t_r Number of units, the resource $r \in R^p \cup R^h$ has been extended in period t.
- RK^t_r Base capacity of resource $r \in R^p \cup R^h$ in period t.
- ERK^t_r Maximally allowed extension of the capacity of the resource $r \in R^p \cup R^h$ in period t.
- RC^t_r Penalty costs per extended resource unit of resource $r \in R^p \cup R^h$ in period t.

Strategic Supply Chain Model from Practice

Mixed integer linear program

Objective function

$$\min \sum_{t\in T}\sum_{\ell\in L}\sum_{p\in P}\left(BC^t_{\ell,p}b^t_{\ell,p} + HC^t_{\ell,p}h^t_{\ell,p}\right) + \quad \text{procurement and production}$$

$$\sum_{t\in T}\sum_{\substack{\ell,\ell'\in L\\ \ell\neq\ell'}}\sum_{p\in P} TC^t_{\ell,\ell',p}x^t_{\ell,\ell',p} + \quad \text{distribution}$$

$$\sum_{t\in T}\sum_{r\in R^h\cup R^p} RC^t_r v^t_r + \quad \text{resource extension}$$

$$\sum_{t\in T}\sum_{\ell\in L}\sum_{p\in P} PDC^t_{\ell,p}z^t_{\ell,p} + \quad \text{unsatisfied demand}$$

$$\sum_{t\in T}\sum_{\ell\in L}\sum_{p\in P} IC^t_{\ell,p}inv^t_{\ell,p} + \quad \text{inventory costs}$$

$$\sum_{t\in T}\sum_{\ell\in S^o} OC^t_\ell y^t_\ell + \sum_{t\in T\setminus\{T\}}\sum_{\ell\in S^c} CC^t_\ell y^t_\ell \quad \text{location decisions}$$

Strategic Supply Chain Model from Practice

Constraints

Flow conservation

procurement, incoming transports, production, inventory last period, incoming goods

$$b^t_{\ell,p} + \sum_{\substack{\ell'\in L\\ \ell\neq\ell'}} x^t_{\ell',\ell,p} + h^t_{\ell,p} + inv^{t-1}_{\ell,p} =$$

outgoing goods

$$\sum_{\substack{\ell'\in L\\ \ell\neq\ell'}} x^t_{\ell,\ell',p} + \sum_{q\in P} a_{\ell,p,q}h^t_{\ell,q} + inv^t_{\ell,p} + D^t_{\ell,p} - z^t_{\ell,p} \qquad \forall \ell,p,t$$

outgoing transports, consumption to production, inventory this period, demand, unsatisfied demand

Strategic Supply Chain Model from Practice

Resources

Production

$$\sum_{t\in T}\sum_{\ell\in L}\sum_{p\in P}\mu_{\ell,r,p}h^t_{\ell,p} \le RK^t_r + v^t_r \qquad \forall r\in R^p$$

Handling

$$\sum_{t\in T}\sum_{p\in P}\left(\sum_{\substack{\ell,\ell'\in L\\ \ell\neq\ell'}}(\lambda^i_{\ell',r,p} + \lambda^o_{\ell,r,p})x^t_{\ell,\ell',p} + \sum_{\ell\in L}\lambda^i_{\ell,r,p}b^t_{\ell,p}\right) \le RK^t_r + v^t_r \qquad \forall r\in R^h$$

Incoming goods and goods issue, respectively, by transports; goods issue by procurement

Feasibility of extension

$$0 \le v^t_r \le ERK^t_r \qquad \forall r\in R^p\cup R^h$$

Strategic Supply Chain Model from Practice

Location decisions

Selectable facilities can be opened and closed, respectively, only once

$$\sum_{t\in T} y_\ell^t \;\le\; 1 \quad \forall \ell \in S^o \qquad \text{and} \qquad \sum_{t\in T} y_\ell^t \;=\; 1 \quad \forall \ell \in S^c$$

Define

$$T_\ell^t = \begin{cases} \{1,\dots,t\} & \text{if } \ell \in S^o \\ \{t,\dots,T\} & \text{if } \ell \in S^c \end{cases}$$

Activities at selectable facilities

Procurement

$$b_{\ell,p}^t \;\le\; M \sum_{\tau\in T_\ell^t} y_\ell^\tau \qquad \forall \ell \in S,\, t\in\mathcal{T},\, p\in\mathcal{P}$$

Strategic Supply Chain Model from Practice

Production

$$h_{\ell,p}^t \;\le\; M \sum_{\tau\in T_\ell^t} y_\ell^\tau \qquad \forall \ell \in S,\, t\in\mathcal{T},\, p\in\mathcal{P}$$

Inventory

$$inv_{\ell,p}^t \;\le\; M \sum_{\tau\in T_\ell^t} y_\ell^\tau \qquad \forall \ell \in S,\, t\in\mathcal{T},\, p\in\mathcal{P}$$

Outgoing distribution

$$x_{\ell,\ell',p}^t \;\le\; M \sum_{\tau\in T_\ell^t} y_\ell^\tau \qquad \forall \ell \in S,\, \ell' \in L,\, t\in\mathcal{T},\, p\in\mathcal{P}$$

Incoming distribution

$$x_{\ell',\ell,p}^t \;\le\; M \sum_{\tau\in T_\ell^t} y_\ell^\tau \qquad \forall \ell \in S,\, \ell' \in L\setminus\{S\},\, t\in\mathcal{T},\, p\in\mathcal{P}$$

Strategic Supply Chain Model from Practice

Integer and non-negativity constraints

$$inv_{\ell,p}^0 \;=\; 0 \qquad \forall \ell \in L,\, p\in\mathcal{P}$$

$$b_{\ell,p}^t,\, h_{\ell,p}^t,\, inv_{\ell,p}^t \;\ge\; 0 \qquad \forall \ell \in L,\, t\in\mathcal{T},\, p\in\mathcal{P}$$

$$0 \le z_{\ell,p}^t \;\le\; D_\ell^t \qquad \forall \ell \ne \ell' \in L,\, t\in\mathcal{T},\, p\in\mathcal{P}$$

$$x_{\ell,\ell',p}^t \;\ge\; 0 \qquad \forall \ell \ne \ell' \in L,\, t\in\mathcal{T},\, p\in\mathcal{P}$$

$$y_\ell^t \;\in\; \{0,1\} \qquad \forall \ell \in L,\, t\in\mathcal{T}$$

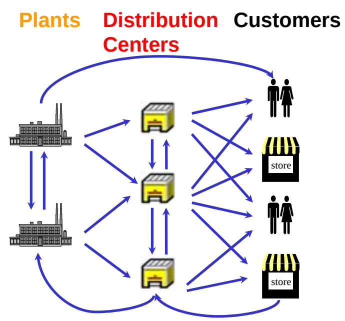
Example

- 10 periods
- 10 products
- 5 plants
- 50 customers
- existing facilities: 10 DCs
- new facilities: 20 potential sites for DCs

→ 10 270 constraints

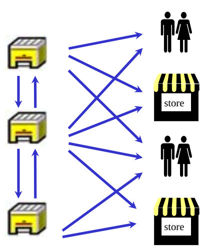
→ 732 810 non-negative variables (dense network)

→ 270 binary variables   status of facilities



Numerical tests

Class 1

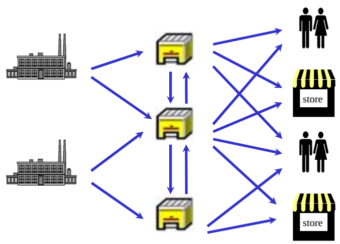


Periods: 3, 4, 5, 6
Products: 5, 10, 15

Customers: 50, 75
DCs: 10 existing
20 new

← location level →

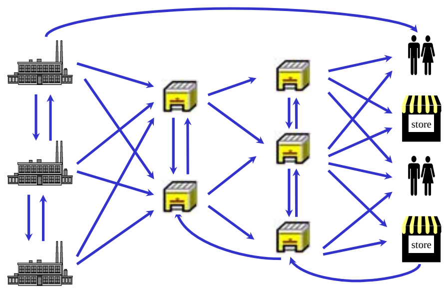
Class 2



Periods: 4
Products: 5, 10
Plants: 5
Customers: 50, 75, 100, 150
DCs: 10 existing
20 new

Numerical tests

Class 3

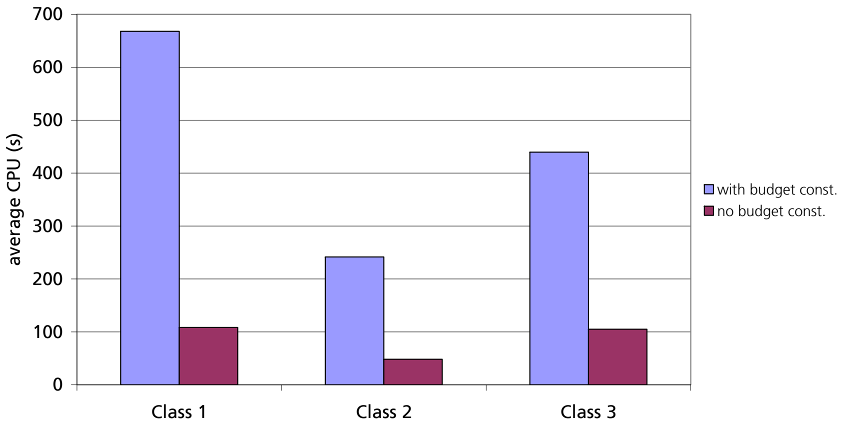


Periods: 3, 4, 5
Products: 5
Plants: 5
Customers: 50, 75
DCs: 20 existing
12 new
← location level

95 randomly generated problems solved optimally with CPLEX® 7.1 (Pentium III, 850 MHz, 1 GB RAM)

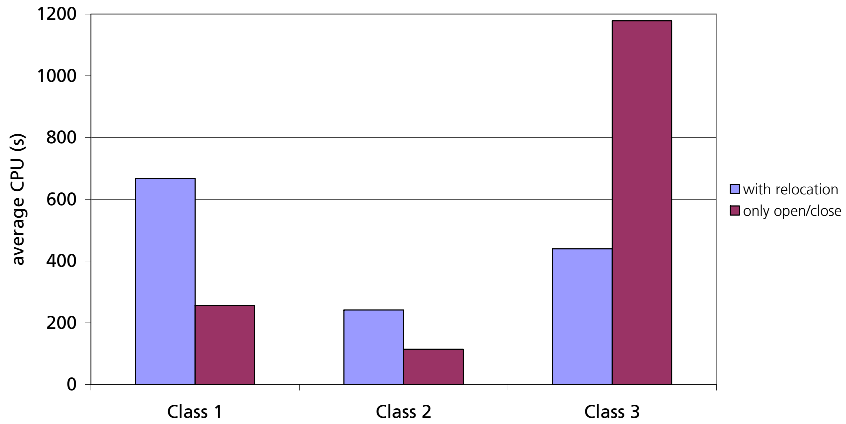
Numerical tests

Impact of budget constraints



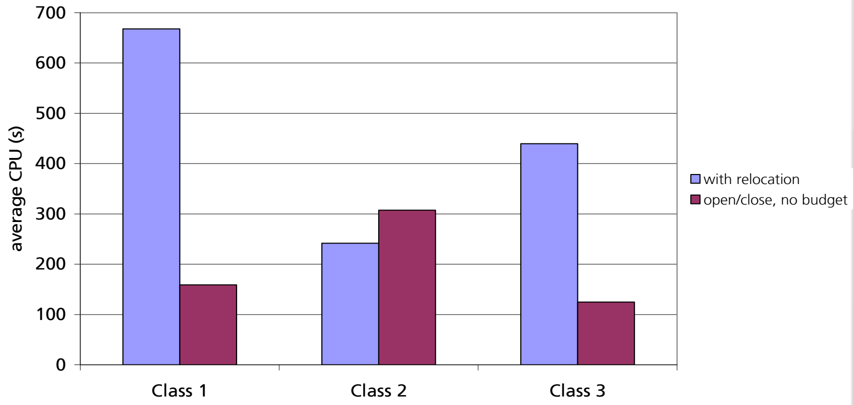
Numerical tests

Facility relocation vs “pure“ open / close facilities



Numerical tests

Facility relocation vs “pure“ open / close facilities & no budget constraints



Location Problems in SCM

Contents

- A Supply Chain Design Problem with facility location, production and transportation activities
- The real problem: Multi-Period Relocation Problems
- Strategic Supply Chain Model from Practice
- Heuristic Solution Procedures
- (Applications and Software)

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	2	3	4	5	periods
existing facility	✓0	✓0	✓1	×0	×0	
new facilities	×0	×0	×0	×0	×0	
	×0	×0	✓1	✓0	✓0	

➡ *for given status matrix the resulting problem is a LP !*

0 no status change
1 status change

✓ open
× closed

Heuristics Approach

LP-based heuristic

Phase 1: (Fast) Construction

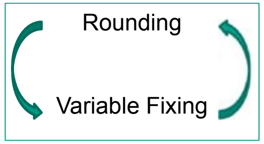
- All status variables are fixed to 0 or 1

Phase 2: Repair / Improvement

- Some fixing decisions made in phase 1 are changed

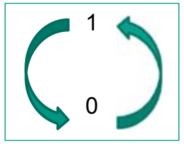
Heuristics Approach

Phase 1: Construction



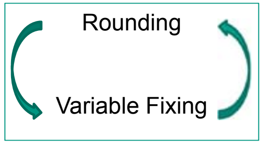
→ Feasible solution with good quality → STOPP
→ Feasible solution with bad quality
→ Infeasible solution

Phase 2: Repair / Improvement



Heuristics Approach

Phase 1: Construction



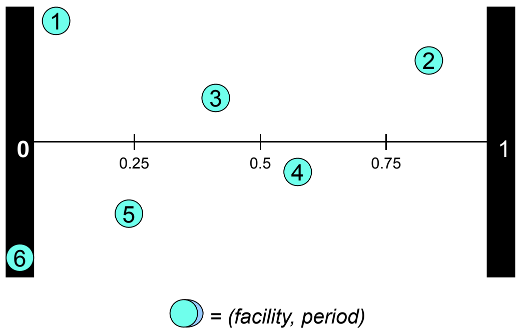
4 Strategies for variable fixing:

- Fixing variables to 0
  - S1 Use lower threshold
  - S2 Select an existing facility
- Fixing variables to 1
  - S3 Use upper threshold
  - S4 Select a potential facility

Heuristics approach

Phase 1: Construction

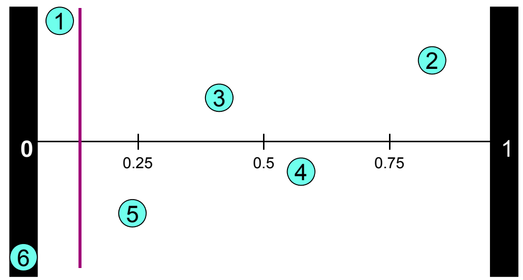
- Start by solving LP-relaxation considering all facility status variables in [0,1]



Heuristics approach

Phase 1: Construction

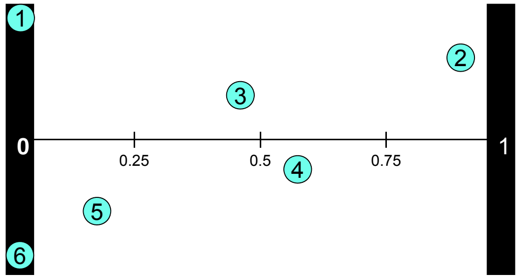
- Variable fixing strategy 1



Heuristics approach

Phase 1: Construction

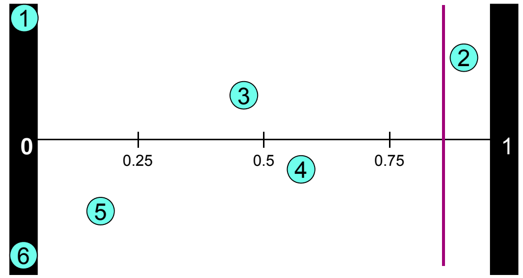
- Solve LP considering all non-fixed facility status variables in [0,1]



Heuristics approach

Phase 1: Construction

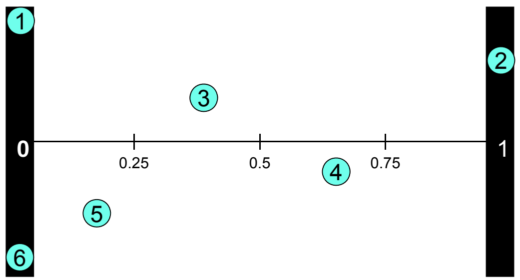
- Variable fixing strategy 3



Heuristics approach

Phase 1: Construction

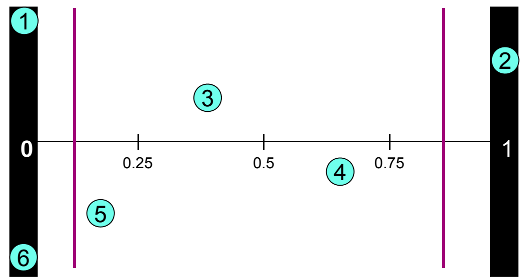
- Solve LP considering all non-fixed facility status variables in [0,1]



Heuristics approach

Phase 1: Construction

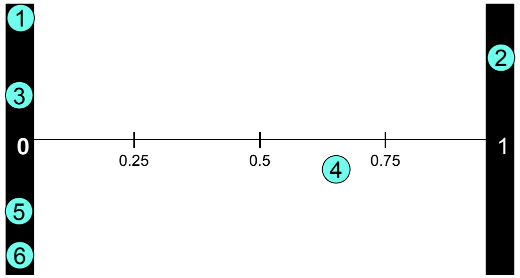
- Variable fixing strategy 2



Heuristics approach

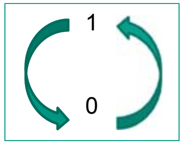
Phase 1: Construction

- Variable fixing strategy 4



Heuristics approach

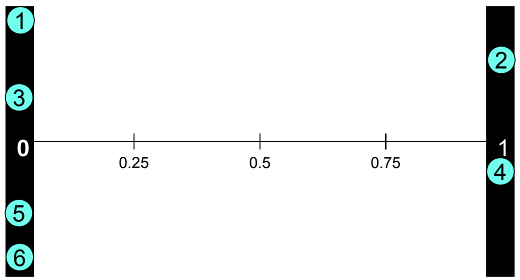
Phase 2: Repair / Improvement



- One or more variables are randomly selected to change from **1** to **0**
- One or more variables are randomly selected to change from **0** to **1**

Heuristics approach

Phase 2: Repair / Improvement



Heuristic approach

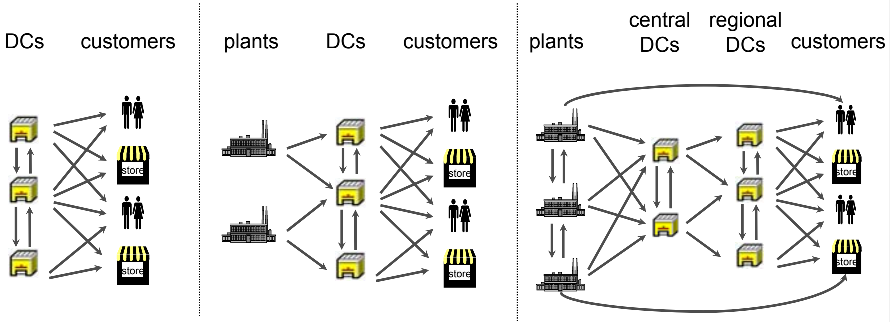
Tuning the heuristic:

- Phase 1:
  - How many variables should be fixed to 0 before a variable is fixed to 1?
  - Values for the upper & lower thresholds: should they change during the procedure?
- Phase 2:
  - How to choose variables for repair / improvement?
- Phases 1 & 2:
  - …

Many degrees of freedom!

A set of preliminary computational experiments were performed

Computational experience



Set 1
45 instances

Set 2
25 instances

From Melo, Nickel and Saldanha-da-Gama (2006)

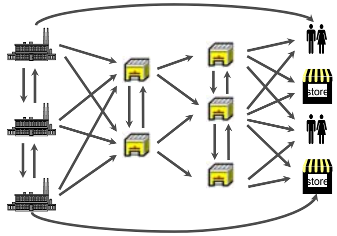
Set 3
45 instances

Newly generated instances

Computational Experience

115 randomly generated instances:

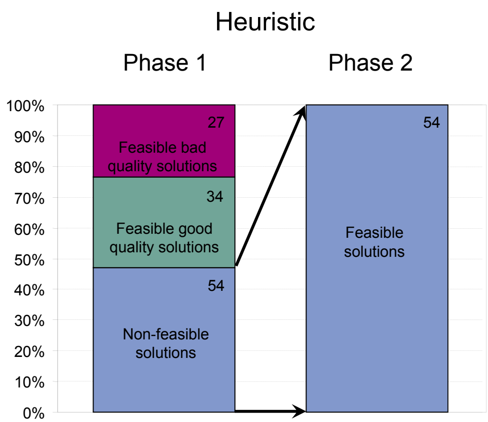
- Periods: 3, 4, 5, 6, 8
- Products: 5, 10, 15, 20, 50
- Plants: 1, 5
- Customers: 50, 75, 100, 150, 200



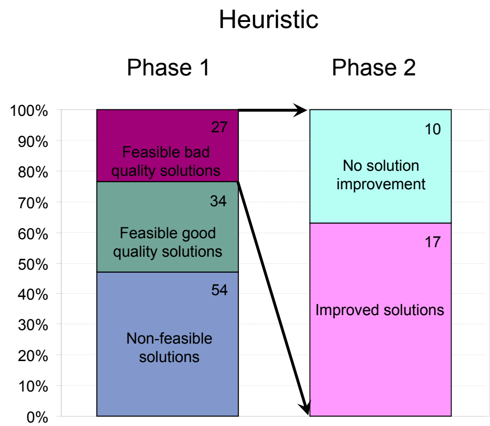
		Existing	New
Relocation	Central DCs	4, 8, 10	8, 12, 20
Levels	Regional DCs	10, 20	20, 30

- Continuous variables: 29000 – 370000
- Binary variables: 90 – 560
- Constraints: 1700 – 20000

Computational experience

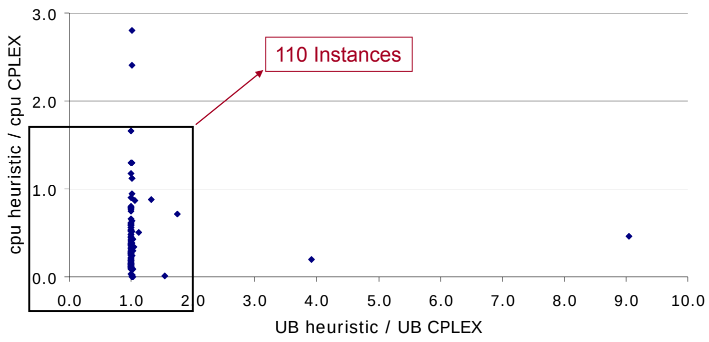


Computational experience



Computational experience

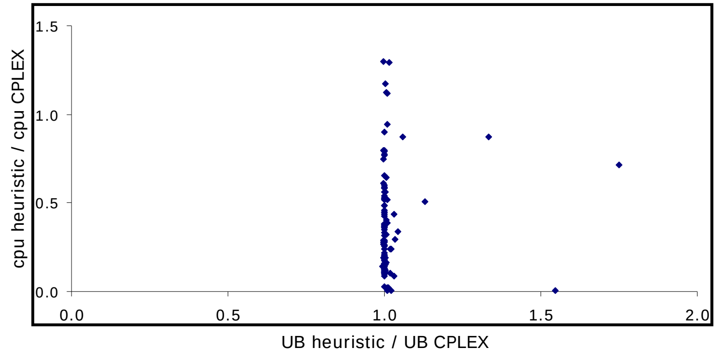
Execution time and solution quality



CPLEX used as a heuristic
(1% gap or time limit 5h)

Computational experience

Execution time and solution quality



Heuristic: - solution quality as good as CPLEX
- much less cpu time than CPLEX

Further Model Enhancements

- Include uncertainties – Stochastic Programming
- Include Nonlinearities
- Location-Routing (from a location perspective)

Solution Approach for a special Multiperiod Case

Lagrangian Relaxation

Assumptions

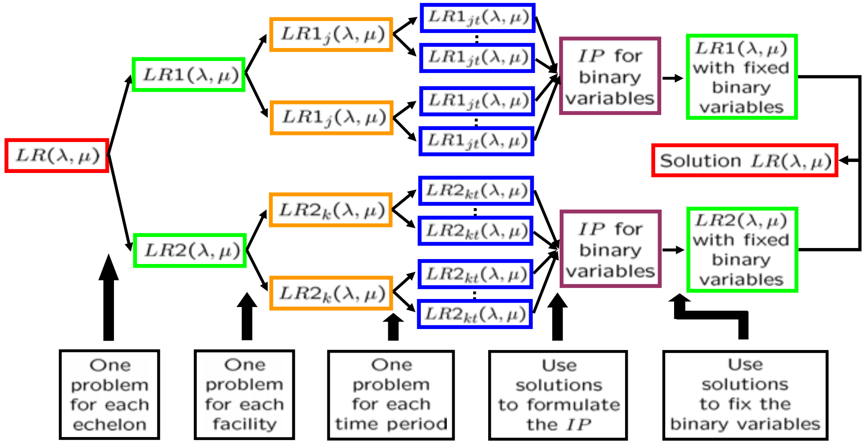
- Two-echelon structure
- inventory is allowed in the warehouses
- location decisions are final:
  if a facility is opened/closed once it can never be closed/reopened again
- Constraints on the minimum number of open facilities at the beginning and the end of the planning horizon

- **Relax the demand satisfaction**

and

- **the flow conservation between the planning periods.**

Lagrangian Relaxation



Reference: Hinojosa, Kalcsics, Nickel, Puerto, Velten, 2008, COR

Solution Approach for a special Multiperiod Case

Problem Types

	Customers	Commodities	Warehouses			Plants		
	$\lvert\mathcal{LC}\rvert$	$\lvert\mathcal{P}\rvert$	$\lvert\mathcal{LW}_o\rvert$	$\lvert\mathcal{LW}_c\rvert$	$\lvert\mathcal{LW}\rvert$	$\lvert\mathcal{LP}_o\rvert$	$\lvert\mathcal{LP}_c\rvert$	$\lvert\mathcal{LP}\rvert$
P1	50	2	14	6	20	14	6	20
P2	75	2	25	15	40	25	15	40
P3	100	10	10	3	13	7	2	9
P4	125	12	12	4	16	8	2	10

Value	Description
H–Gap	Average percentage gap between the objective value of the heuristic solution and the lower bound resulting from the *Subgradient Optimization*
E–Gap	Average percentage gap between the objective values of the heuristic and the optimal solution found by *CPLEX*
CPU–E	Average CPU time needed to find the optimal solution
CPU–H	Average CPU time needed to find the heuristic solution
N	Average number of iterations performed to find the heuristic solution

Solution Approach for a special Multiperiod Case

Summary of Computational Results

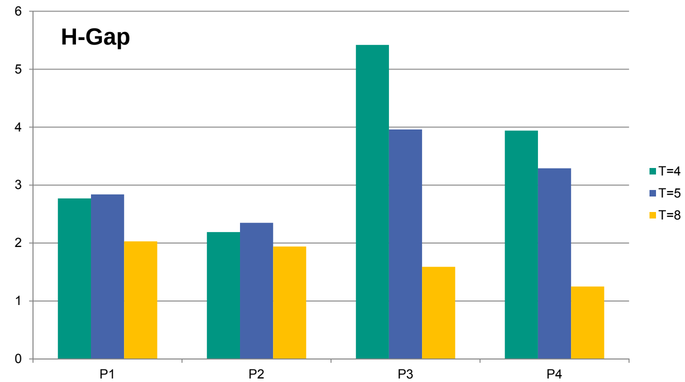
- (Average over 5 Instances / Problem Type and Time Periods)

		P1	P2	P3	P4
$T=4$	H-Gap	2,77	2,19	5,42	3,94
	E-Gap	1,09	1,07*	0,12	0,099
	CPU-E	1523	7200*	2331	3369
	CPU-H	48,72	587,1	161,2	926,2
	N	271	736	44	427
$T=5$	H-Gap	2,84	2,35	3,96	3,29
	E-Gap	1,19*	1,19*	0,18*	0,075*
	CPU-E	5095*	7200*	3577*	5033*
	CPU-H	68,88	1048	307	1035
	N	316	657	44	52
$T=8$	H-Gap	2,03	1,94	1,59	1,25
	E-Gap	0,53*	0,61*	0,098*	0,02*
	CPU-E	6148*	7200*	3620*	6768*
	CPU-H	236	1871	1053	3938
	N	293	441	44	52

* at least one example could not be solved to within the time limit optimality

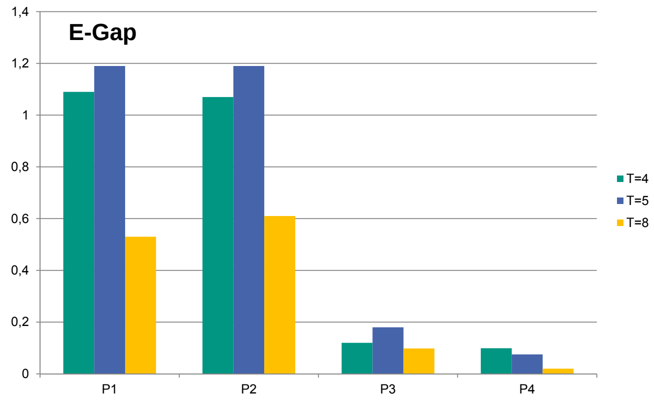
Solution Approach for a special Multiperiod Case

Summary of Computational Results



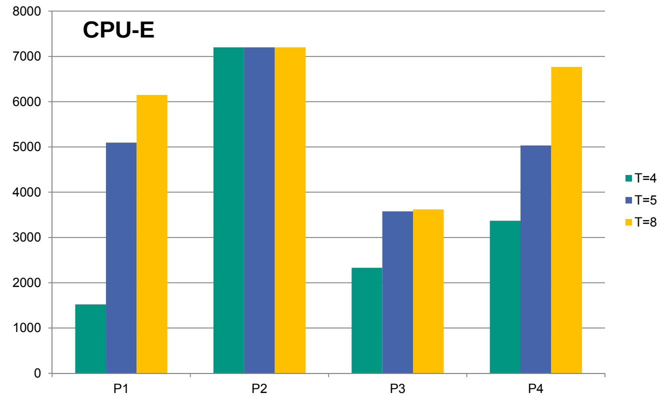
Solution Approach for a special Multiperiod Case

Summary of Computational Results



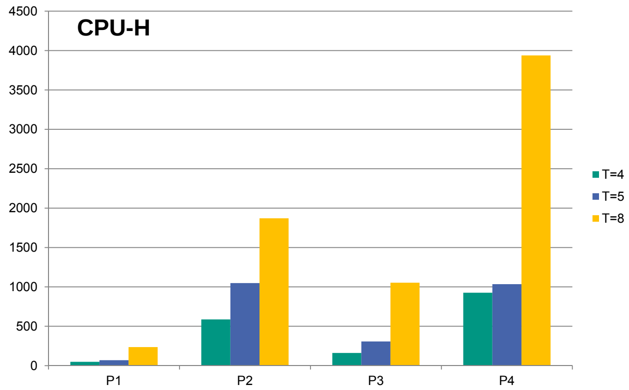
Solution Approach for a special Multiperiod Case

Summary of Computational Results



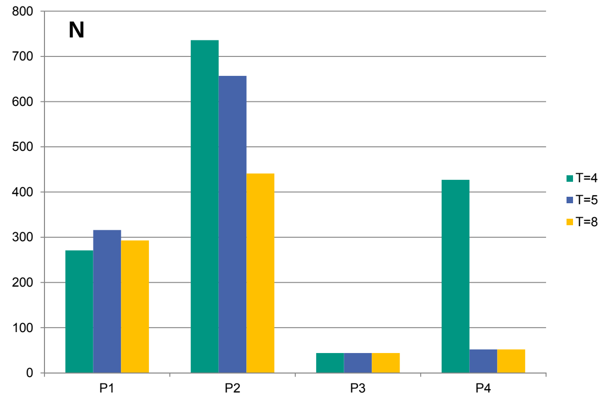
Solution Approach for a special Multiperiod Case

Summary of Computational Results



Solution Approach for a special Multiperiod Case

Summary of Computational Results



Location Problems in SCM

Contents

- A Supply Chain Design Problem with facility location, production and transportation activities
- The real problem: Dynamic Relocation Problems
- Strategic Supply Chain Model from Practice
- Heuristic Solution Procedures
- Applications and Software

Take Over Scenario in the Steel Industry

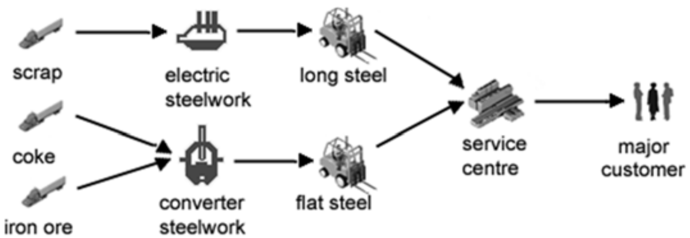
Nickel, Velten, Weimerskirch, 2005 and 2007

Problem Description

- Steel company is a merger of 3 huge steel companies
- Multiple synergy effects are expected
- World leader in steel production p.a. but less than 5 % market share → no monopoly
- Entering new markets is an ultimate strategic objective
- Possibility to take over another steel company
- Where and when should capacity be shifted? Which facilities should be opened and closed, respectively?
- How should the capacity be shifted from existing facilities to new ones without interrupting the supply chain activities or without breaking the budget and capacity restrictions?
- Is it profitable to take over the foreign company in order to use its additional capacities and to include its supply chain?

Take Over Scenario in the Steel Industry

Supply Chain



- Steel company SC: 63 operating facilities
- Potential new facilities: 13 locations
- Take over candidate SC: 13 operating facilities

Analytical Approach for WEEE Network Design

Nickel, Velten, Verter, Weimerskirch, 2008

Problem Description

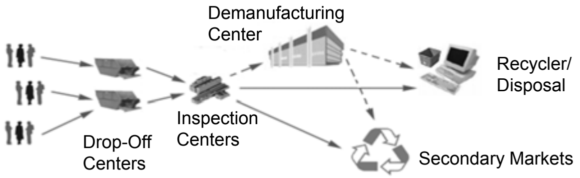
- WEEE Directive (Waste Electrical and Electronic Equipment) is setting collection, recycling and recovery targets for all types of electrical goods
- Existing infrastructure incorporating collection points, inspection and recycling facilities needs to be redesigned
- The responsibility of the WEEE is imposed on the producers
- The municipalities are responsible for the drop off centers
- Do we need more or less, bigger or smaller inspection centers?
- Is it economically reasonable to operate a demanufacturing facility?
- Where and when should capacity be shifted?
- Which facilities should be opened and closed, respectively?

Analytical Approach for WEEE Network Design

Min. objective function
(disposal / treatment + collecting + inventory + operating costs)

→ Constraints categories:

a)flow conservation
b) quotas for secondary markets
c) capacity relocation
d) capacity restriction
e) econ. reasonable minimum throughput
f) facility location
g) budget restrictions
h) non-negativity and integrality



Location Planning for Petrol Stations

Consideration of Geo-Data

Horstmann, Nickel, van Bonn, Ziegler 2007

Questions

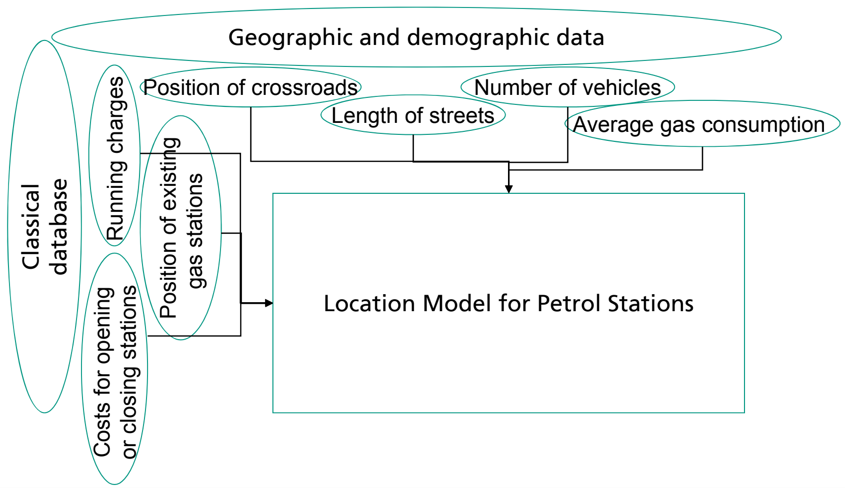
- Which data may support location planning and how can we integrate these data in existing location models?
- Which geographic and demographic data are usually available?
- Where can we get these data from?
- How can we govern the huge amount of geographic and demographic data?
- For how far into the past do we need the data and how far into the future is our location planning reliable?

Location Planning for Petrol Stations

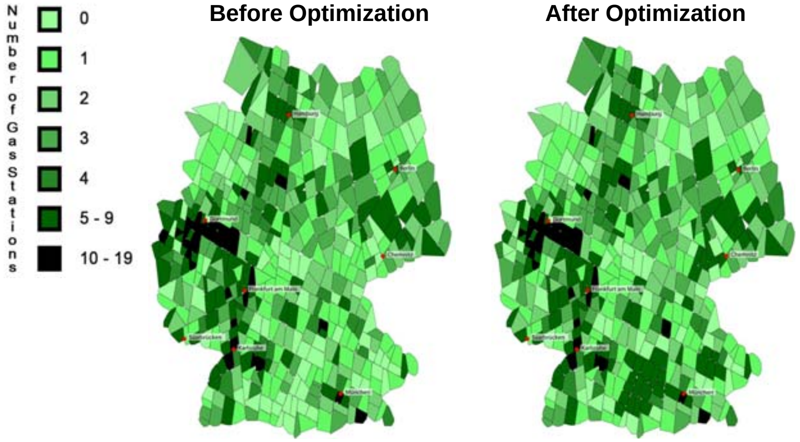
Advantages

- Some geographic and demographic data are widely available, all over the world.
- These data provide a wider data base, if the classical database is unsatisfyingly.
- They allow better forecasts of the expected trends, since they were elevated and safed for years.
- The additional information may help the user to come to more reliable and safer decisions.

Location Planning for Petrol Stations



Case Study - Gas Stations



References

- T. Bender, H. Hennes, J. Kalcsics, T. Melo and S. Nickel, „Location Software and Interface with GIS and Supply Chain Management, Facility Location: Applications and Theory, Springer, (2002).

S. Nickel, S. Velten, G. Weimerskirch, " Strategische Supply-Chain Entscheidungen in der Stahlindustrie - Eine Fallstudie –„, in H.O. Günther, D. C. Mattfeld and L. Suhl (editors): Supply Chain Management and Logistik, Physica-Verlag (2005).

- M.T. Melo, S. Nickel and F. Saldanha da Gama, „Dynamic multi-commodity capacitated facility location: A mathematical modeling framework for strategic supply chain planning", Computers and Operations Research 33: 181-208 (2006).
- Y. Hinojosa, J. Kalcsics, S. Nickel, J. Puerto and S. Velten, „Dynamic Supply Chain Design with Inventory", Computers and Operations Research 35: 373-391 (2008).
- M.T. Melo, S. Nickel and F. Saldanha da Gama, „Facility Location and Supply Chain Management – A Review", European Journal of Operational Research 196:401-412 (2009).

ANT