Experiences with supply chain management in Swedish forest industries

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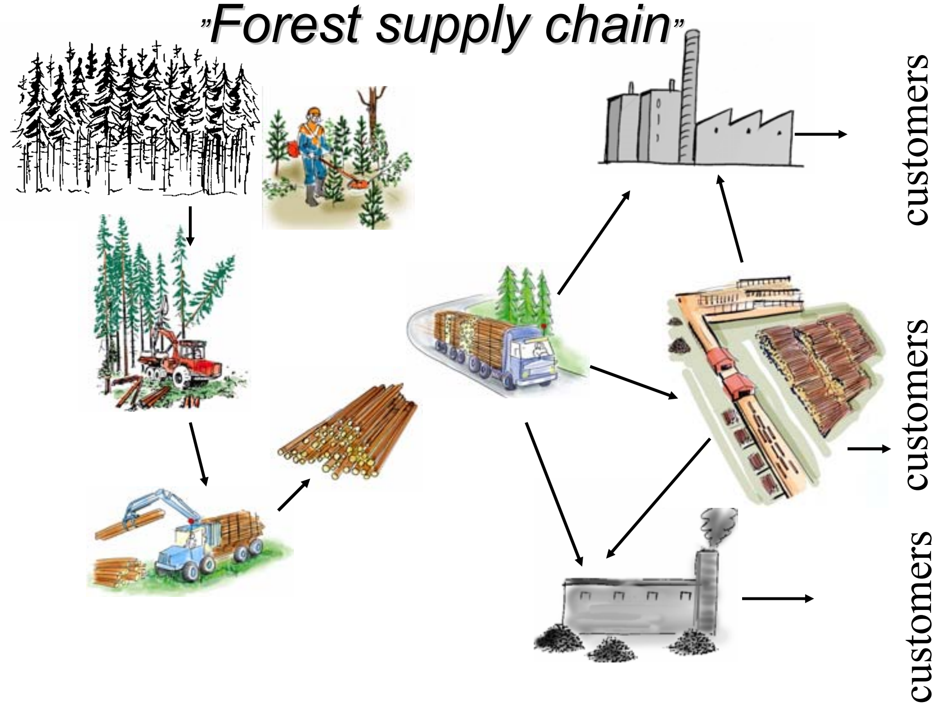
Outline

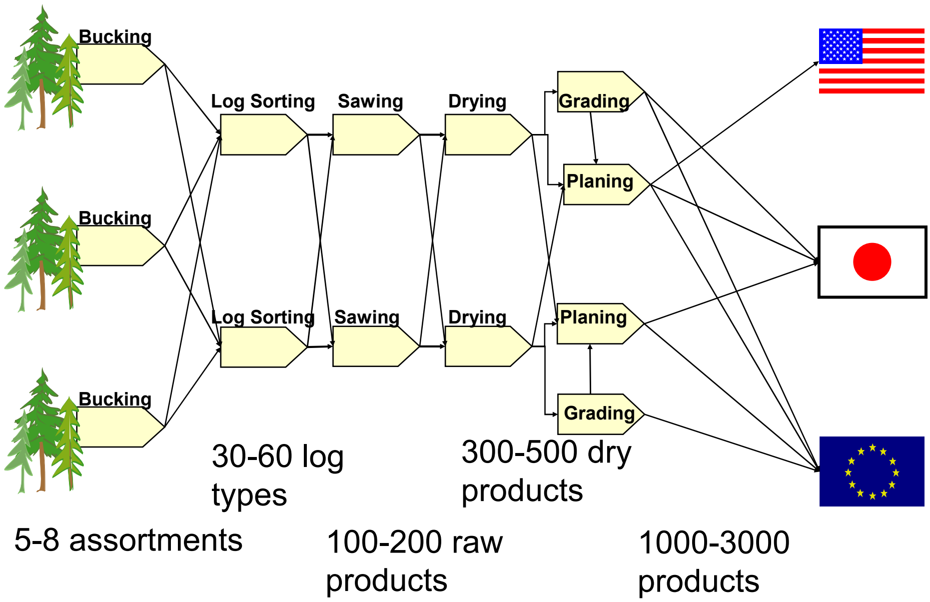
- Forest supply chain – wood flow
- Supply chain modules
  - Transportation and harvesting
  - Integrated logistics
  - Supply chain planning
  - Process control
- Summary

Forest supply chain – wood flow

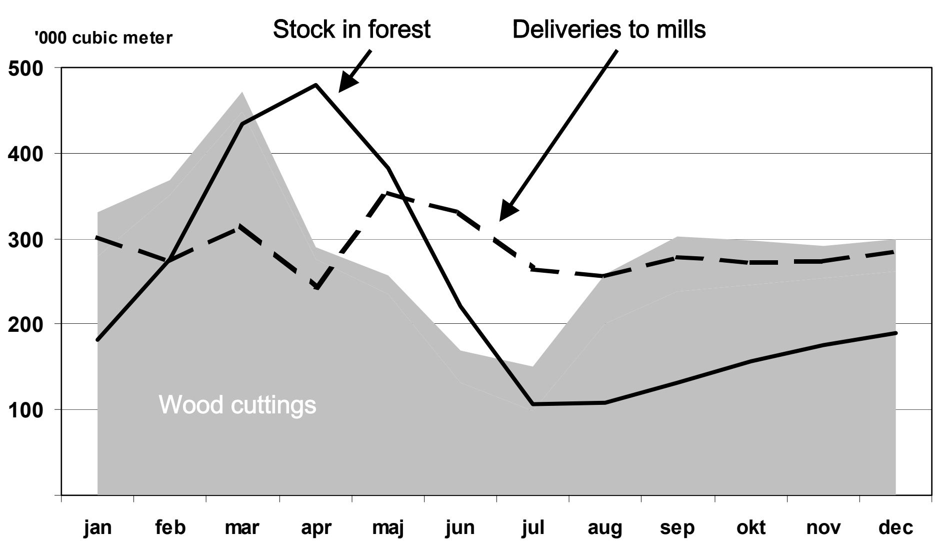
"Forest supply chain"



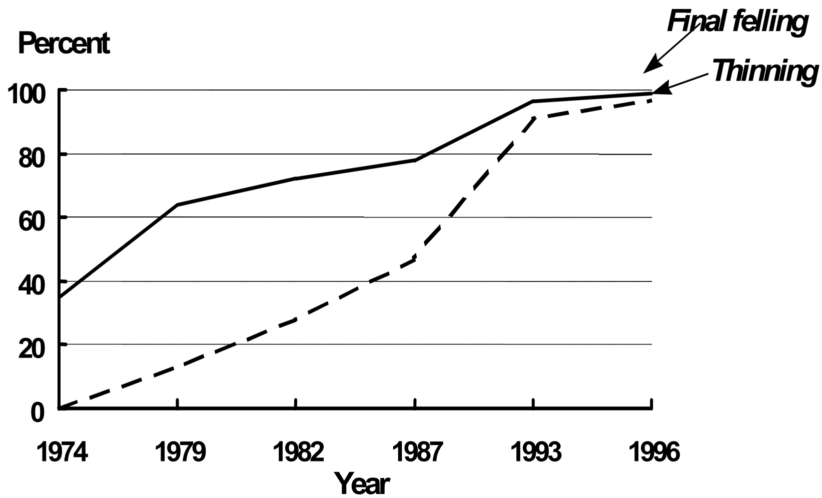
Divergent flows



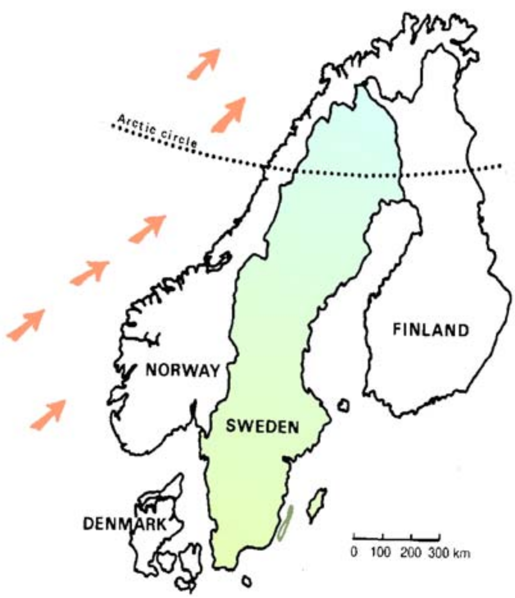
Unbalanced annual harvesting

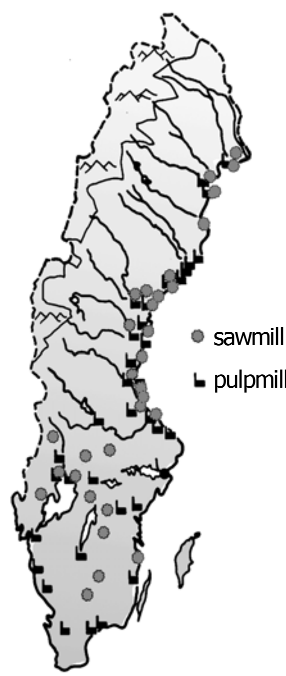


Mechanization levels in Swedish forestry



Geographical features





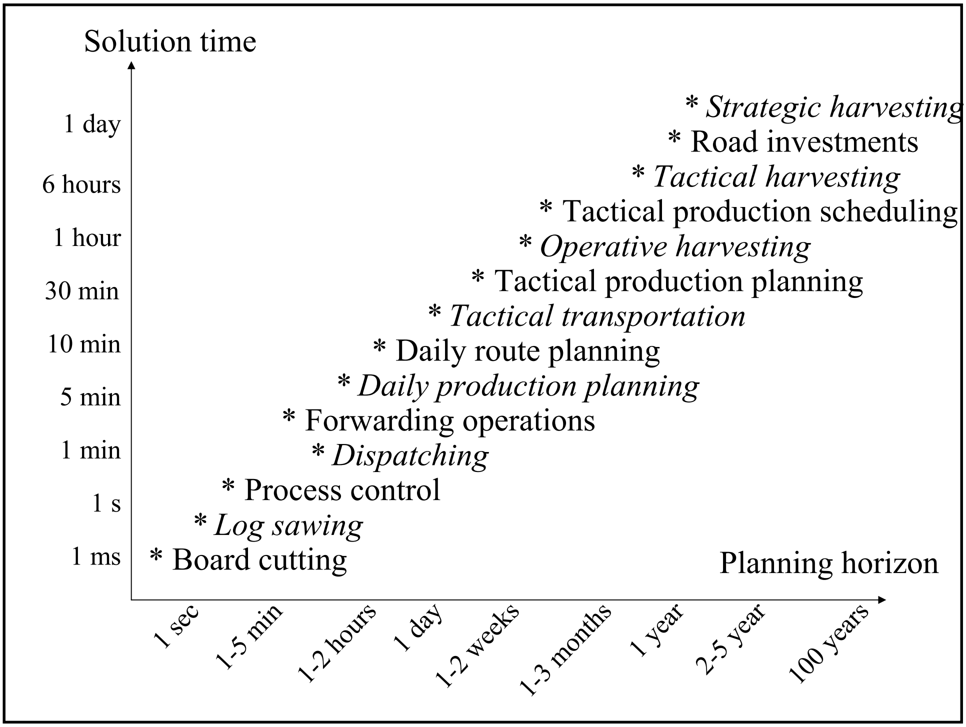
Industry participants

- Forest companies and associations,
  - owning forests and pulp/paper/saw mills.
- Independent sawmills, without any large forests
- Independent forest owners not connected with any mills
- Loggers and transporters

→ Often decentralised management

Planning modules (supply chain matrix)

	Forest management	**Transportation and routing**	**Production**
Strategic > 5 years	*Planting, Valuation, Long term harvesting*	*Road building, Fleet management, Trains?, Terminals?*	*Investment planning*
Tactical 1/2 – 5 years	*Annual harvest plans*	*Road upgrade, Equipment, Train scheduling*	*Annual production planning*
Operational 1 - 180 days	*Crew scheduling, Harvest sequencing*	*Catchment areas, Back-hauling, scheduling*	*Lot sizing, Scheduling*
Online < 1 day	*Bucking*	*Truck dispatching*	*Process control, Roll cutting, Cross-cutting*



Current development

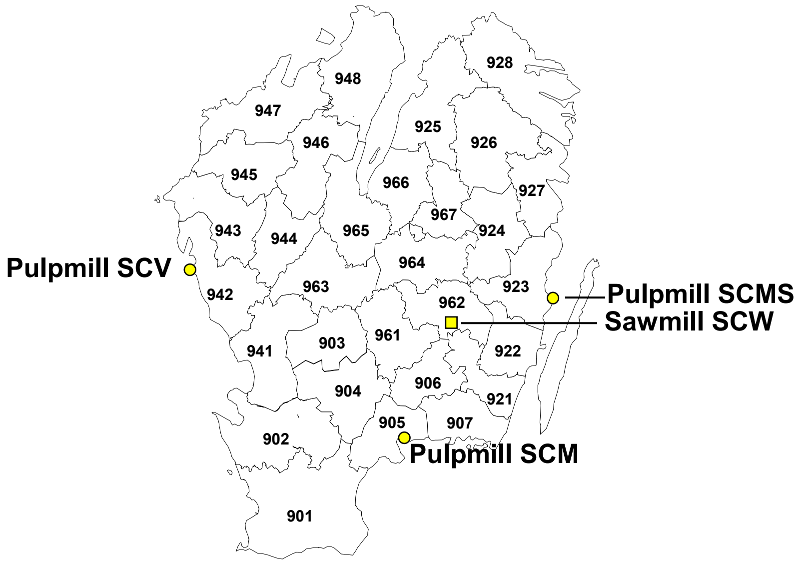
- Companies follow each other in terms of development
- Development of integrated support system for the entire chain but with different modules
- Modules are often based on manual interference but OR techniques is making advances

Transportation and harvesting modules

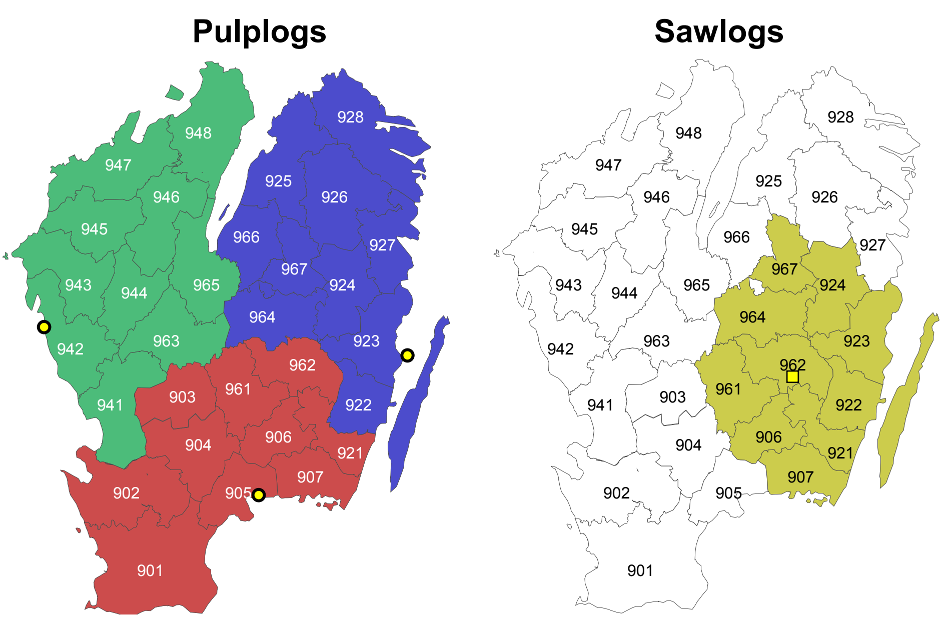
Some facts

- The forest industry represents a major part (25%) of the demand for transportation of goods in Sweden.
- The cost of transportation represent one third of the total cost of raw material, round wood, to the forest industry.

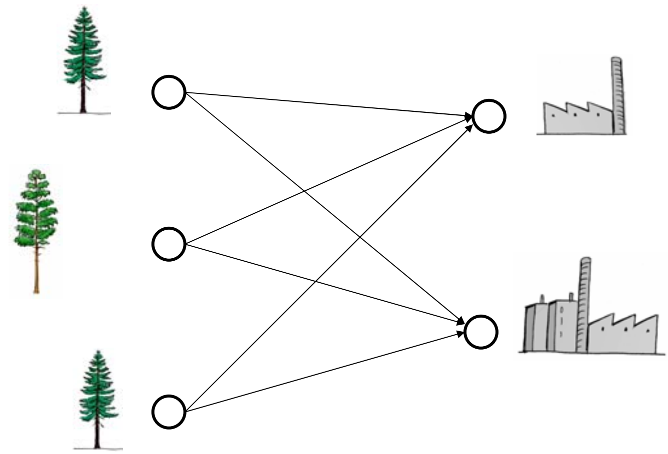
Mills and forest districts



Catchment areas



Multicommodity transportation problem



x_{ijk} = flow from supply point i to demand point j with assortment k

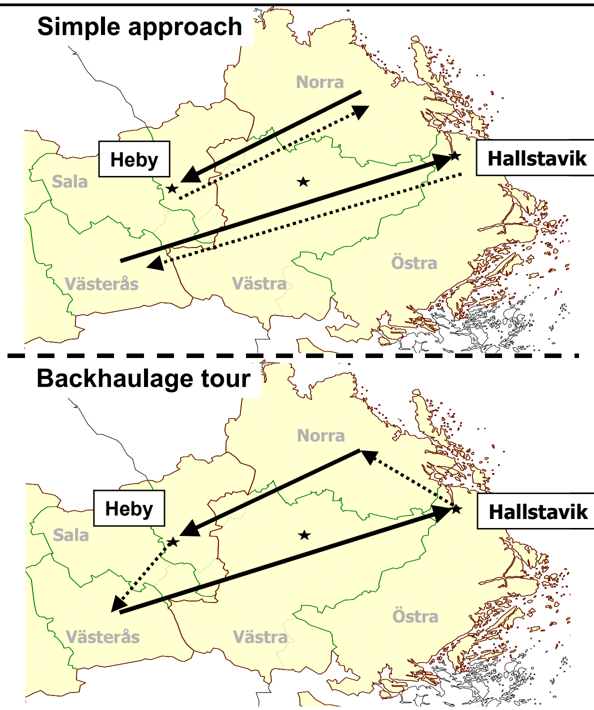
Mathematical model – transportation problem

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

$$\sum_{j\in J} x_{ijk} \le s_{ik}, \quad \forall\ i\in I, k\in K \qquad \text{(supply)}$$

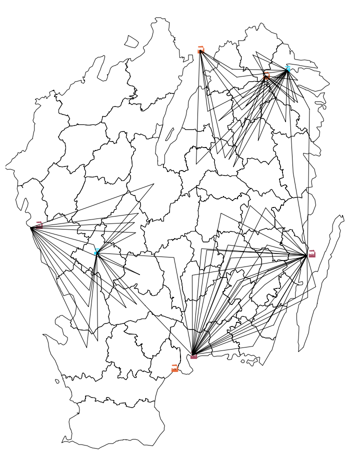
$$\sum_{i\in I} x_{ijk} = d_{jk}, \quad \forall\ j\in J, k\in K \qquad \text{(demand)}$$

$$x_{ijk} \ge 0,\ \forall\ i\in I, j\in J, k\in K$$

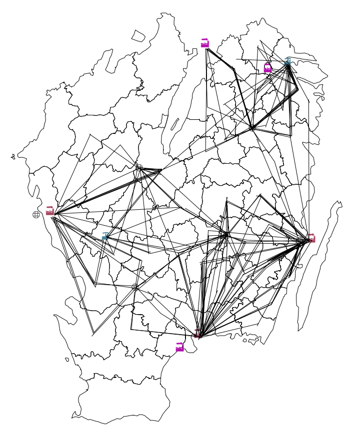


Backhauling case from southern part in Sweden

No sawmills



With sawmills



Mathematical model – backhaulage problem

$$\min \sum_{i\in I}\sum_{j\in J}\sum_{k\in K} c_{ijk}x_{ijk} + \boxed{\sum_{l\in L} d_l y_l}$$

$$\sum_{j\in J} x_{ijk} + \boxed{\sum_{l\in L} a_{ikl} y_l} \le s_{ik}, \quad \forall\ i,k \qquad \text{(supply at harvest areas)}$$

$$\sum_{i\in I} x_{ijk} + \boxed{\sum_{l\in L} b_{jkl} y_l} = d_{jk}, \quad \forall\ j,k \qquad \text{(demand at industries)}$$

$$x_{ijk}, y_l \ge 0, \ \forall\ i\in I, j\in J, k\in K, l\in L$$

Backhaulage planning results

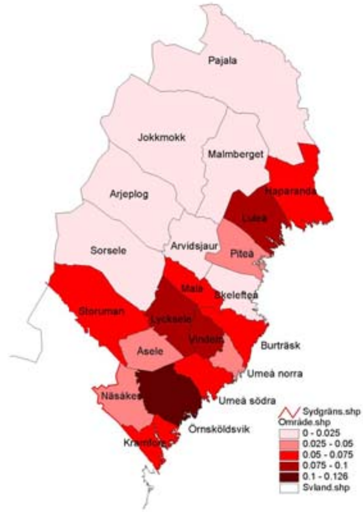
Savings

- Cost - 6 %
- Empty driving - 30 %
- Time - 9 %
- Fuel - 9 %

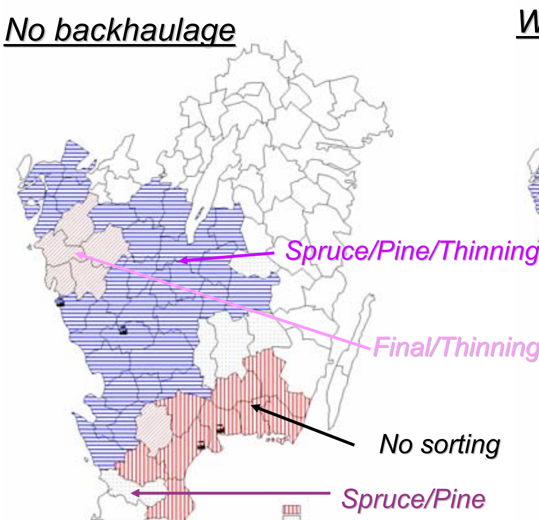
Case study ”Transportsamordning Nord”

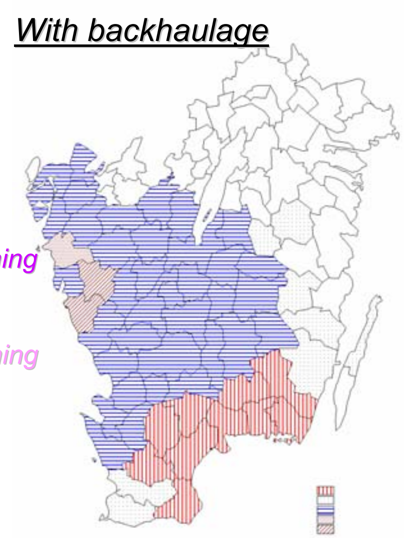
Results

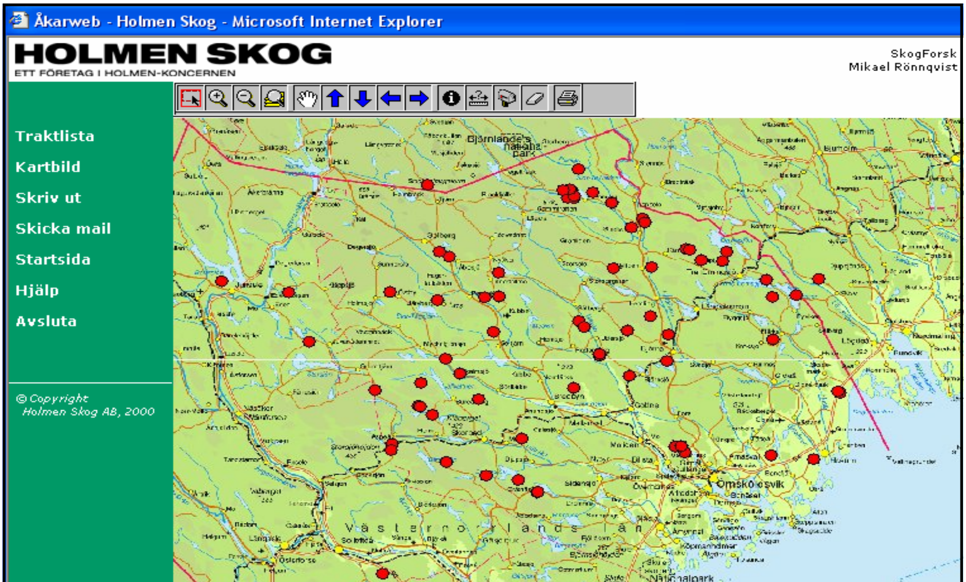
- backhaulage, 46 % of volumes
- Empty driving - 24 %
- Time – 9 %
- Fuel – 7 %



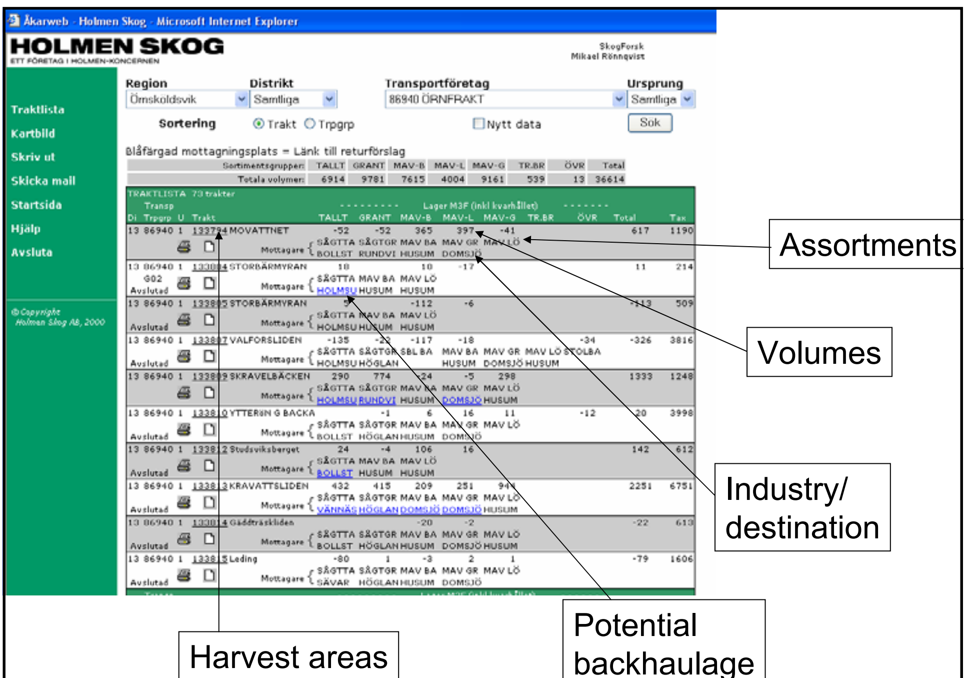
Sorting decisions

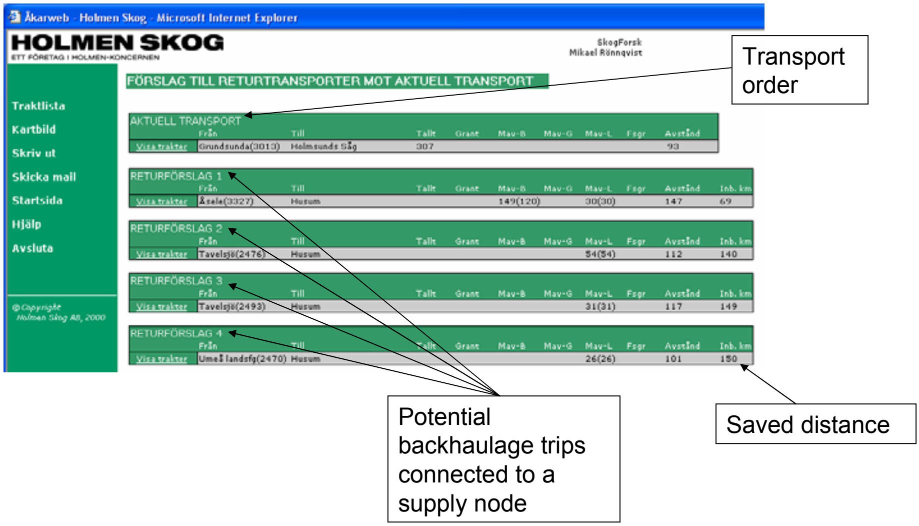






Åkarweb – a web based planning system using optimized backhaulage plans





Åkarweb – current usage

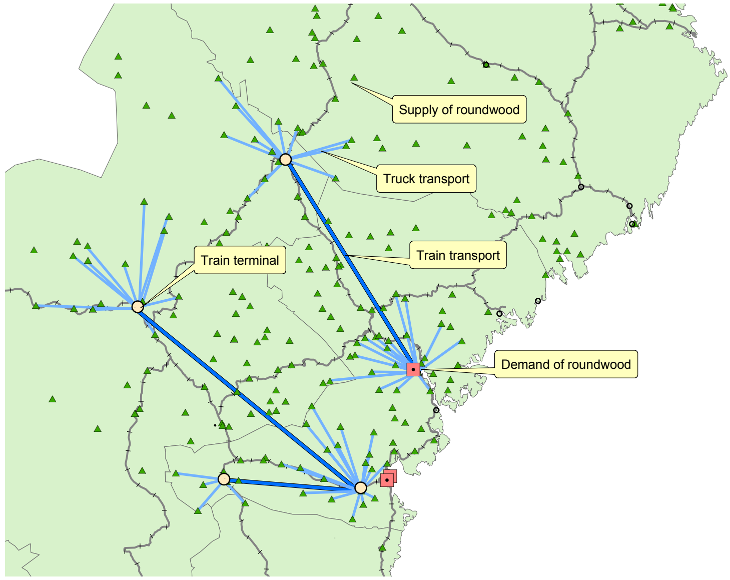
- Online information system
  - Continuous updates of supplies, demands…
  - Total of 180 trucks connected
- Experiences:
  - Less administration
  - 15% less empty driving
  - 6-7% cost savings

Integrated logistics - FlowOpt

Supply chain planning modules

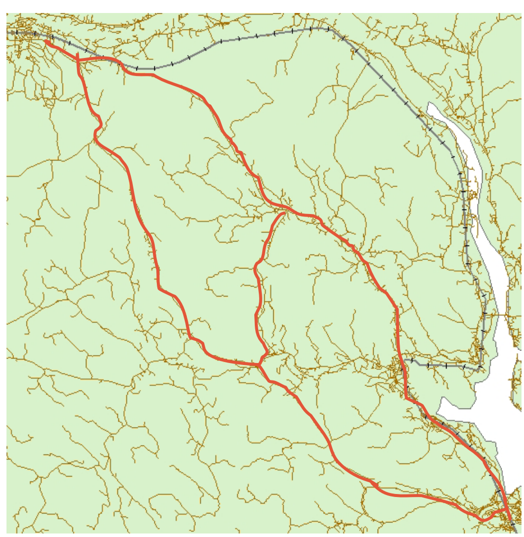
	Forest management and harvesting	Transportation and routing	Production
Strategic planning > 5 years	Planting, Evaluation, long term harvesting	**Road building, road upgrading, fleet management, train, terminals**	Investment planning
Tactical planning 6 months – 5 years	Annual harvest plans	**Road upgrade, Equipment and fleet utilization, train schedules**	Annual production planning
Operative planning 1 day – 6 months	Crew scheduling, Harvest sequencing	**Catchment areas, back-haulage planning**, scheduling	Lot sizing, scheduling
Online planning < 1 day	Bucking	Truck dispatching	Process control, Roll cutting, Cross-cutting

Integrated supply chains



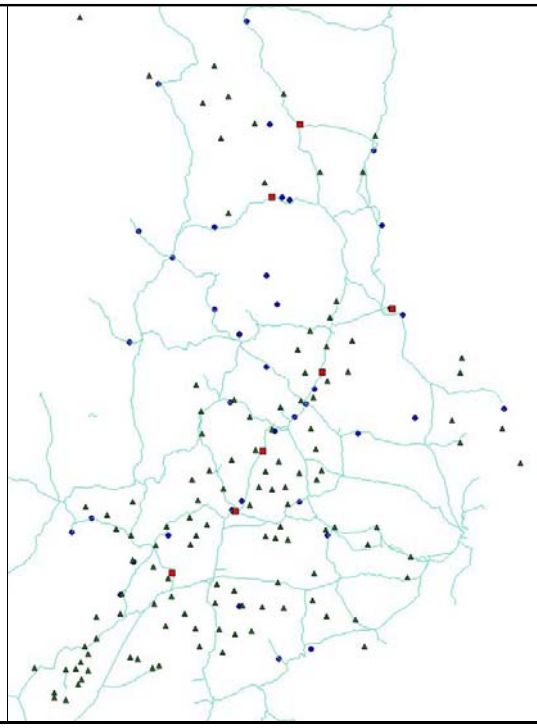
Route selection with road database

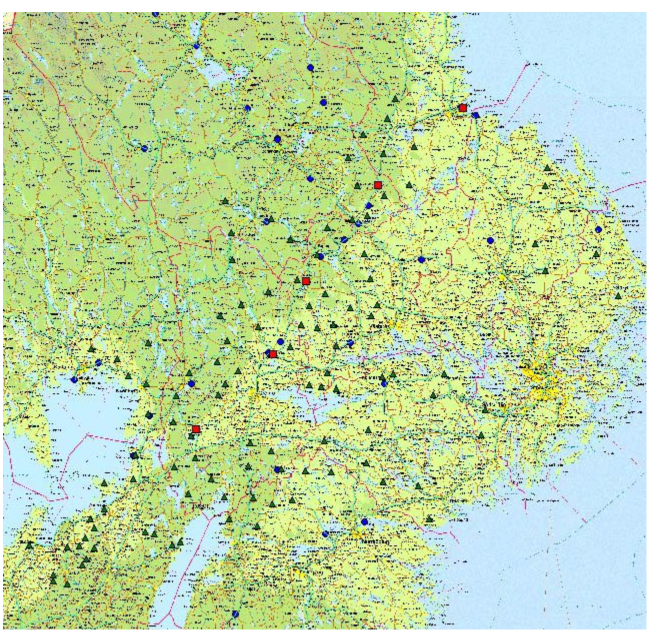
- Length
- Road class
- Speed limit
- Surface
- Road width
- Owner

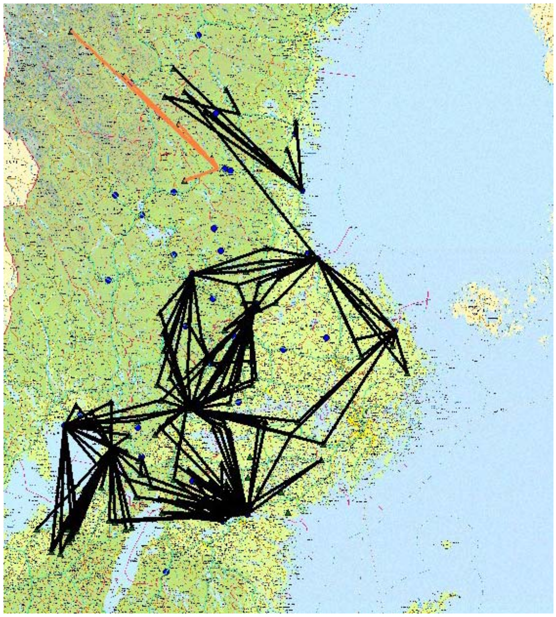


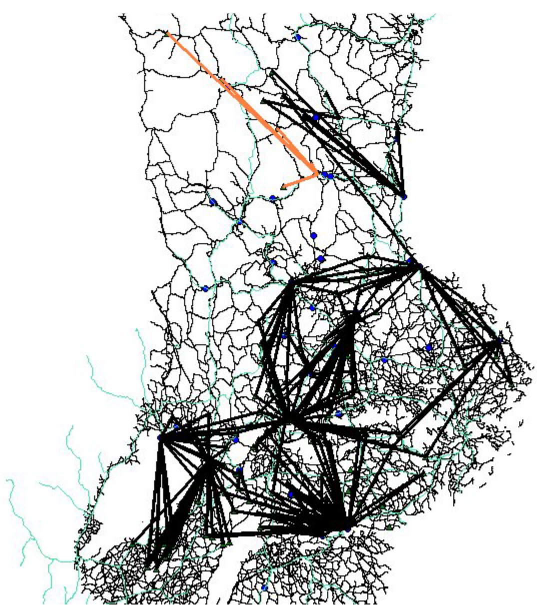
Recent case

- 140 supplies
- 1500 piles
- 52 industries
- 220 demands
- 10 terminals
- 5 train routes
- 12 assortments
- 8 assortment groups
- 5 scenarios









Optimization

- Approx. 100,000 variables (flow)
- Approx. 3,000 constraints
- Approx. 30 million backhaulage tours
- Solution time:
  - (no backhaulage): < 10 seconds
  - (backhaulage): up to 1 hour
- Results
  - Overall saving using train & trucks: 5-10%
  - Addional saving using backhaulage tours: 2-5%

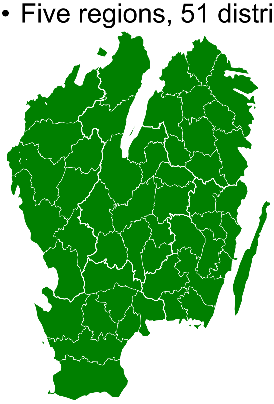
Case studies with FlowOpt

- Co-operation between companies to coordinate transportation
- Co-ordinate between companies to swap pulp-logs
- Integrate harvesting, sorting and paper production
- Terminal location

Supply chain planning

The Södra Group

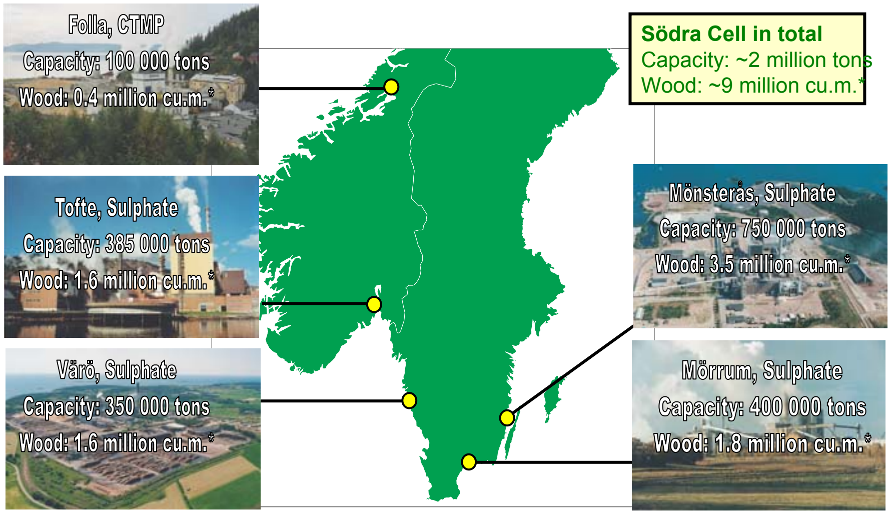
Södra Skog
- Purchasing and trading
- 12,5 million cubic meters
- Five regions, 51 districts



Södra Cell
- Processing wood into pulp
- Five mills
- Producing 2 million tons
- Processing 9 million cubic meters

Södra Timber
- Processing logs into sawn timber
- Six mills
- Producing 1 million cubic meters
- Processing 2 million cubic meters

Södra Cell - Production units

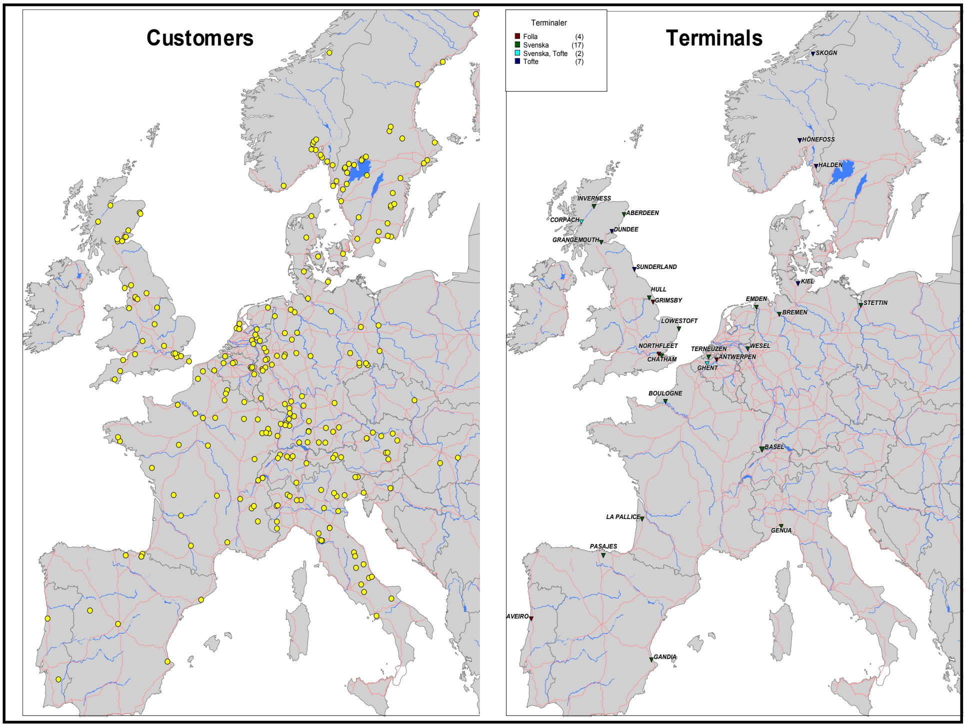


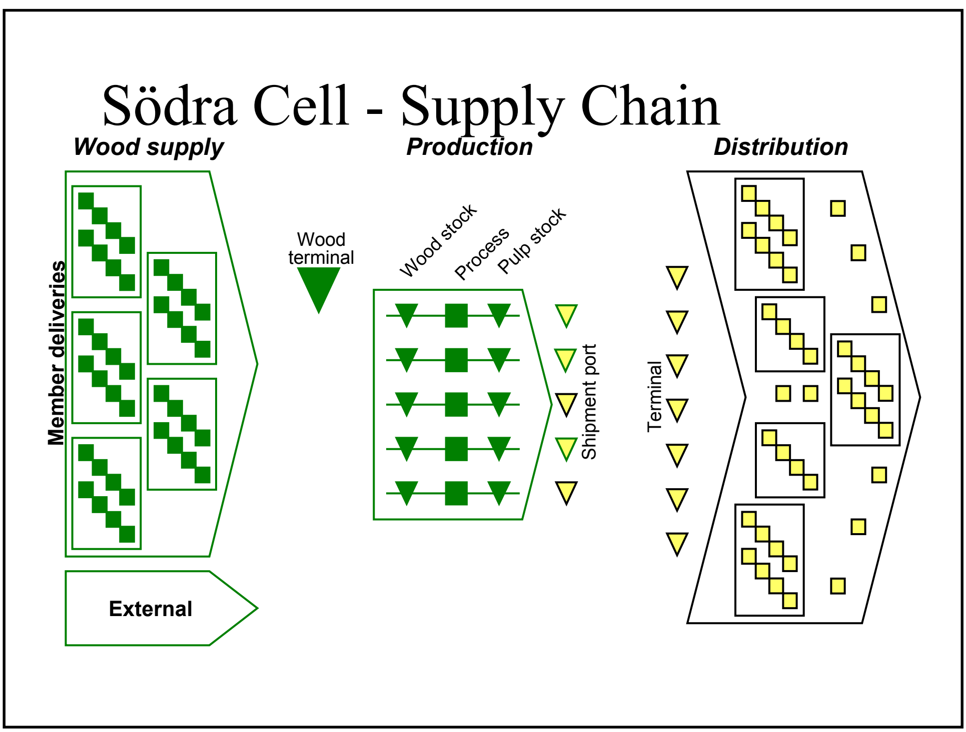
**cu.m. = cubic meters, solid under bark*

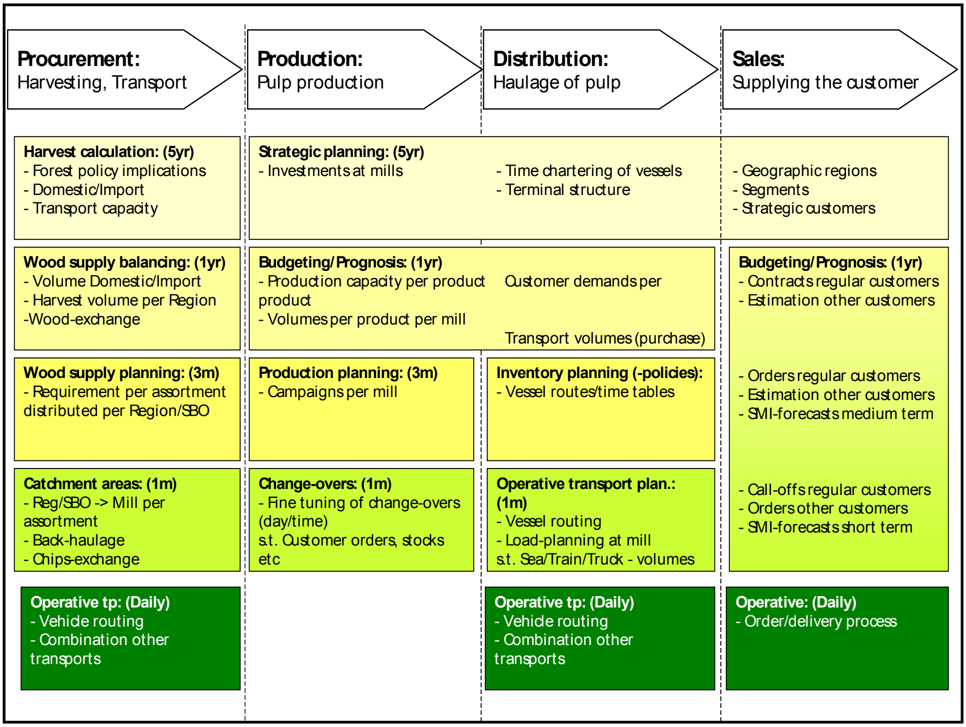
Supply chain - Transports

To the mills

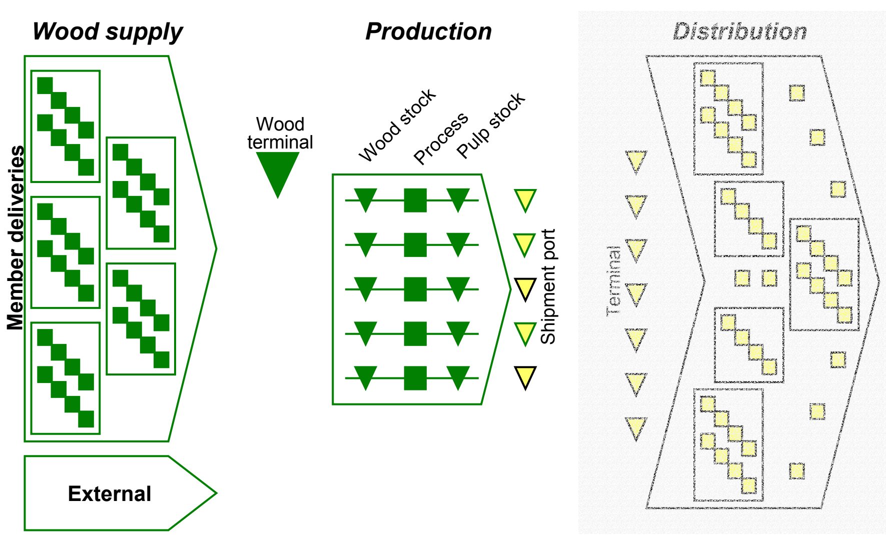
From the mills

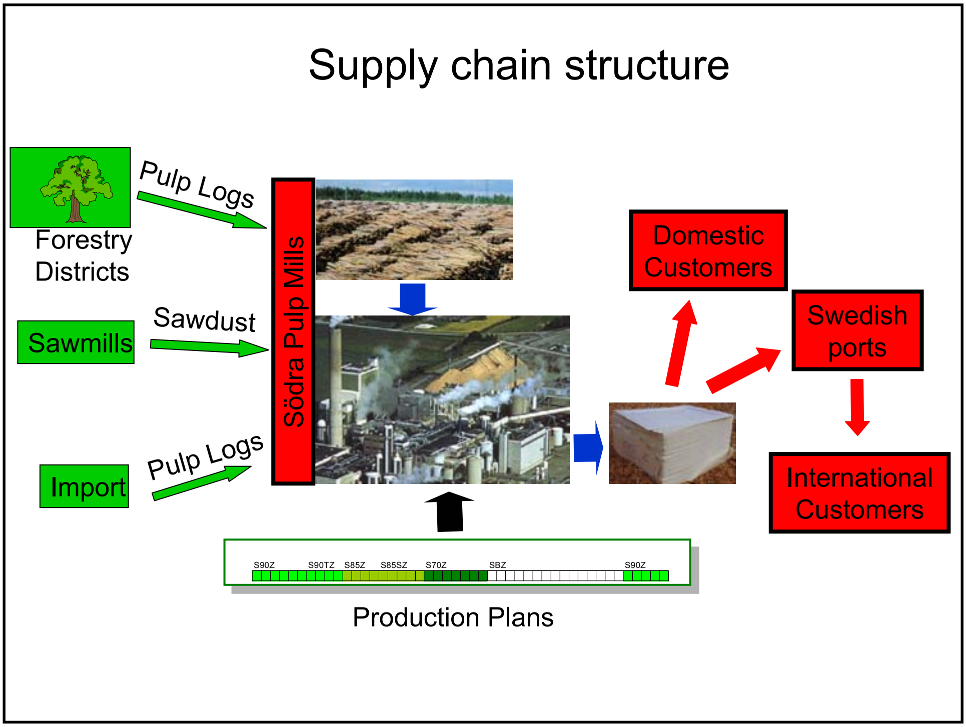

Customers
Terminals
Terminaler
Folla (4)
Svenska (17)
Svenska, Tofte (2)
Tofte (7)
SKOGN
HÖNEFOSS
HALDEN
INVERNESS
ABERDEEN
CORPACH
DUNDEE
GRANGEMOUTH
SUNDERLAND
HULL
GRIMSBY
LOWESTOFT
NORTHFLEET
CHATHAM
TERNEUZEN
ANTWERPEN
GHENT
WESEL
EMDEN
BREMEN
KIEL
STETTIN
BOULOGNE
BASEL
LA PALLICE
PASAJES
GENUA
AVEIRO
GANDIA

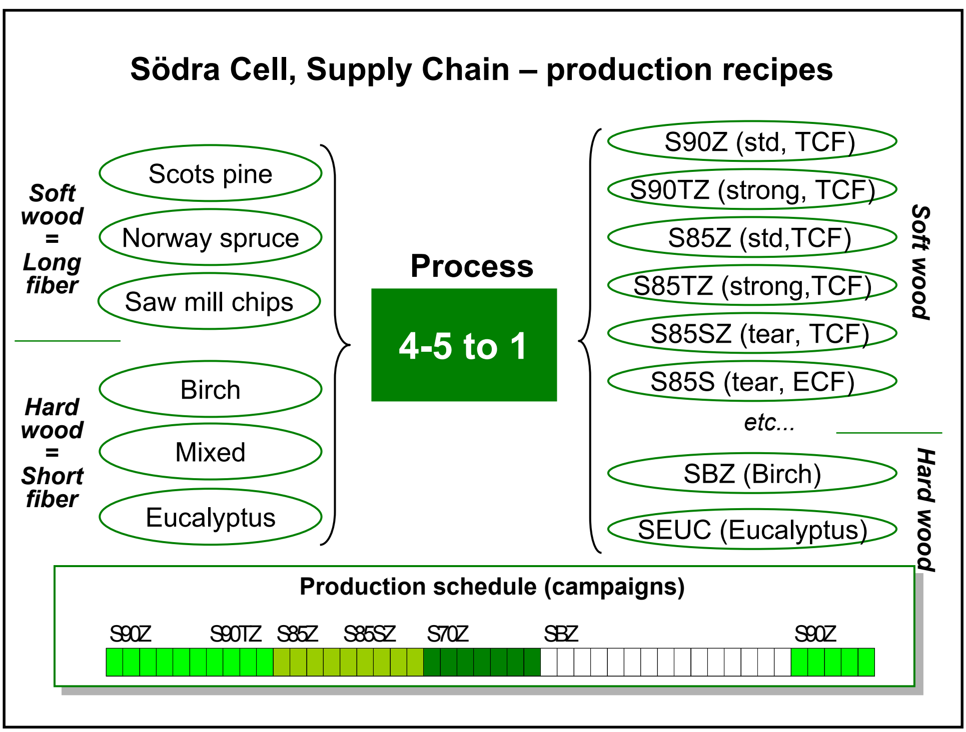

Södra Cell - Supply Chain
Wood supply
Production
Distribution
Member deliveries
External
Wood terminal
Wood stock
Process
Pulp stock
Shipment port
Terminal



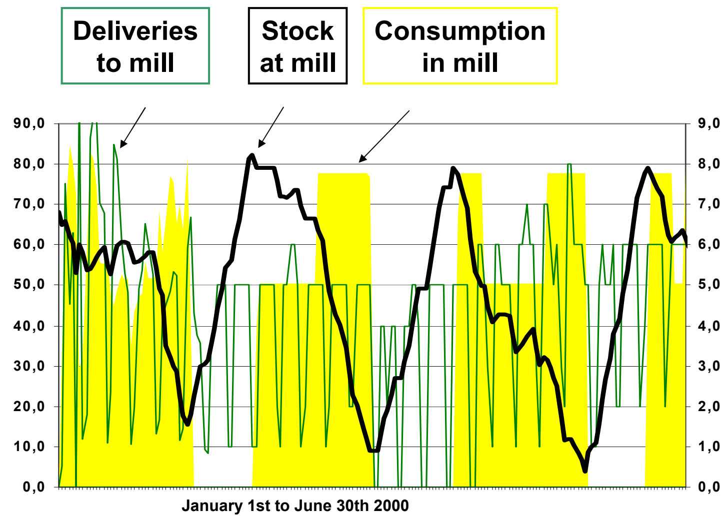
Supply chain - Production planning




Supply chain structure
Pulp Logs
Forestry Districts
Sawdust
Sawmills
Pulp Logs
Import
Södra Pulp Mills
Domestic Customers
Swedish ports
International Customers
S90Z S90TZ S85Z S85SZ S70Z SBZ S90Z
Production Plans


Södra Cell, Supply Chain – production recipes
Soft wood = Long fiber
Scots pine
Norway spruce
Saw mill chips
Hard wood = Short fiber
Birch
Mixed
Eucalyptus
Process
4-5 to 1
S90Z (std, TCF)
S90TZ (strong, TCF)
S85Z (std,TCF)
S85TZ (strong,TCF)
S85SZ (tear, TCF)
S85S (tear, ECF)
etc...
Soft wood
SBZ (Birch)
SEUC (Eucalyptus)
Hard wood
Production schedule (campaigns)
S90Z S90TZ S85Z S85SZ S70Z SBZ S90Z

Daily variation due to batch (campaign) production: Assortment pine



$$l^F_{ia,t-1} + H_{iat} - \sum_{j \in M} x_{ijat} = l^F_{iat} \quad \forall i,a,t$$

$$l^H_{jp,t-1} + w_{jpt} - v_{jpt} = l^H_{jpt} \quad \forall j,p,t$$

$$\sum_{a \in A} f_{ja} \le T^M_j \quad \forall j$$

$$0.9 f_{ja} \ge \sum_{i \in F} x_{ijat} \le 1.1 f_{ja} \quad \forall j,a,t$$

$$\sum_{j \in M} \sum_{a \in A} x_{ijat} \le T^D_i \quad \forall i,t$$

$$\sum_{j \in M} y_{jdpt} = D^D_{dpt} \quad \forall d,p,t$$

$$\sum_{j \in M} v_{jpt} = D^E_{pt} \quad \forall p,t$$

- *No systems from SAP, i2, …*
- *PC based system*

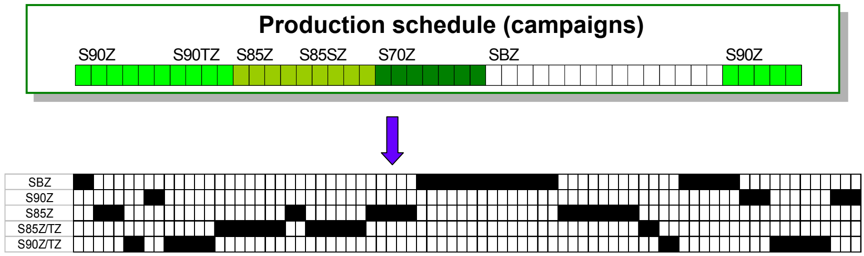
- Daily time discretisation
- Minimize total supply chain cost
- Production variables: z
  - Column generation of 3-month plans
- Flow and storage variables
  - Inflow, storage, transportation
- Constraints
  - Flow conservation, capacities, demand
- Branch and price & constraint branching
- Initial tests gave 7 days solution time
- Aggregation of time periods

$$l^A_{ja,t-1} + \sum_{i \in F} x_{ijat} - \sum_{q \in Q_j} \sum_{r \in R_j} R^{in}_{jra} \delta_{jqrt} z_{jq} - l^A_{jat} = 0 \quad \forall j,a,t$$

$$l^P_{jp,t-1} + \sum_{q \in Q_j} \sum_{r \in R_j} R^{out}_{jrp} \delta_{jqrt} z_{jq} - w_{jpt} - \sum_{d \in D} y_{jdpt} - l^P_{jpt} = 0 \quad \forall j,p,t$$

$$\sum_{q \in Q_j} z_{jq} = 1 \quad \forall j$$

Solution method - column generation



Each campaign has a minimum and maximum duration

There is a fixed cost to switch products

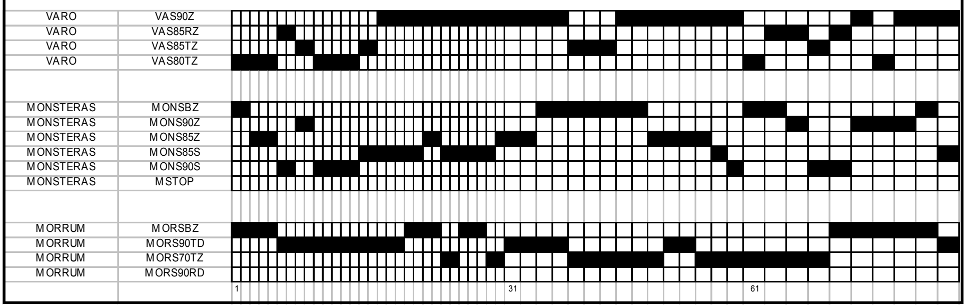
Solution balances transportation and setup costs

Test case

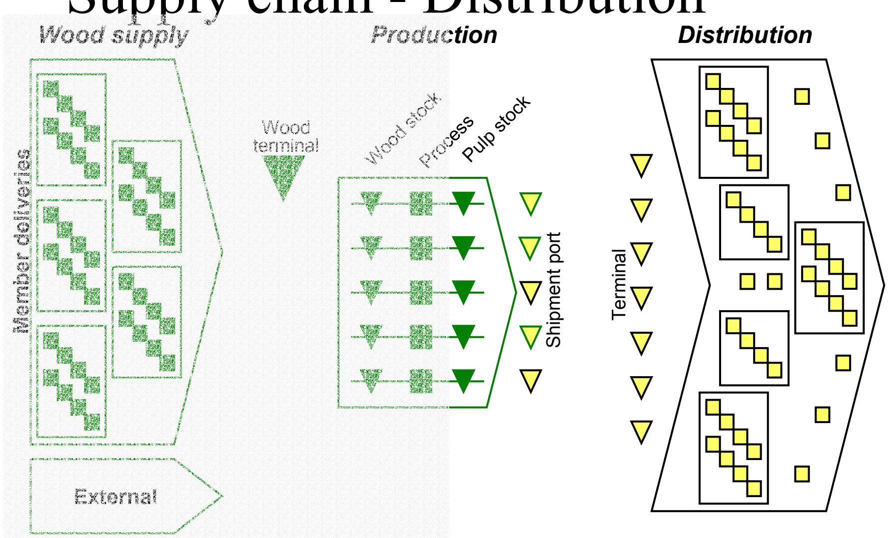
- 3 Swedish pulp mills
- Comparison with manual plan (Jan-April 2001)
- 10 forest districts producing 4 log types
- 15 products (specific recipes per pulp mill)
- 90 days planning giving 55 time periods
- Model A:
  - Master: 9,500 constraints; 31,800 variables+1,500 generated
  - Sub: Production Plan Generator:
    - 300,000 arcs (full subproblem)
    - 5,500 arcs (lower bounds on campaign length)
- Model B:
  - Master: 14,000 constraints; 35,000 variables

Production plans

- Comparison with manual plans
- Strategic implications regarding campaign scheduling
- Challenges:
  - model more parts of the supply chain

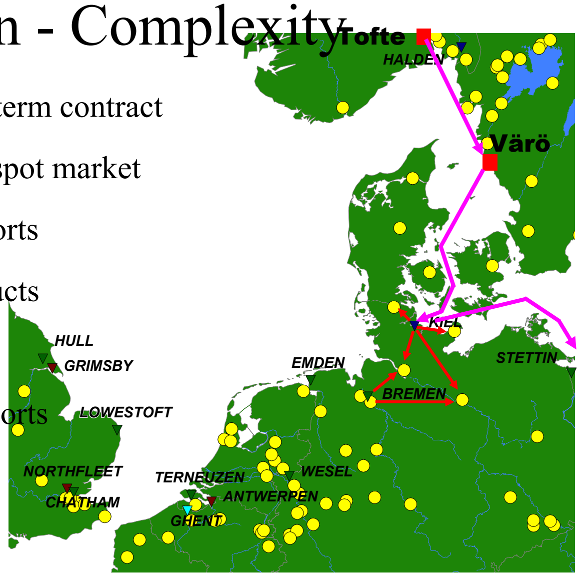


Supply chain - Distribution

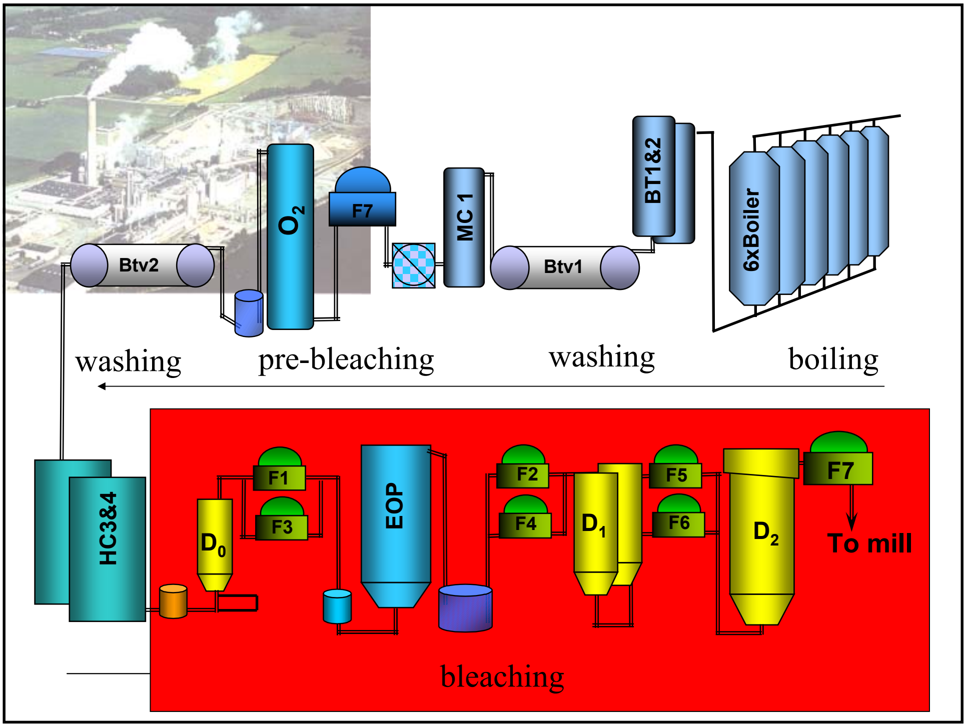


Distribution - Complexity

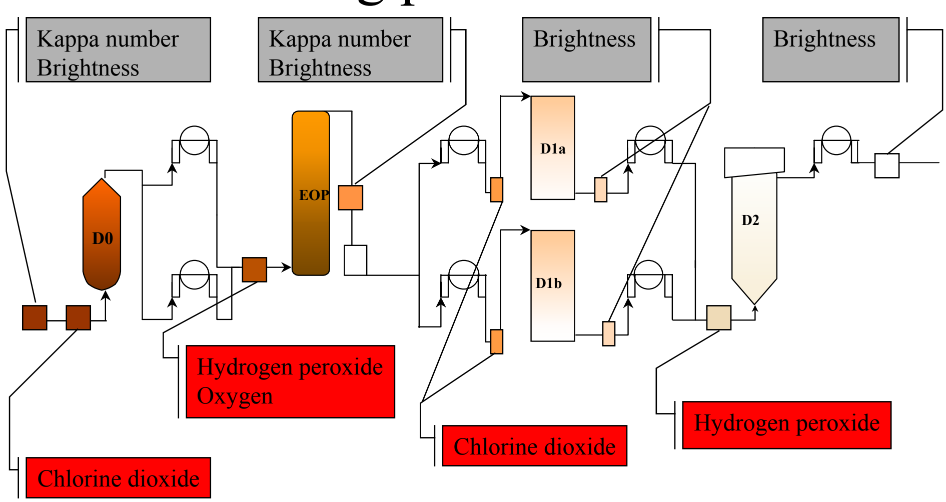
- Three vessels on long term contract
- Additional vessels on spot market
- Train and truck transports
- Several different products
- Supply ≈ Demand
- Alternative shipment ports
- Alternative terminals



Process control



Bleaching process



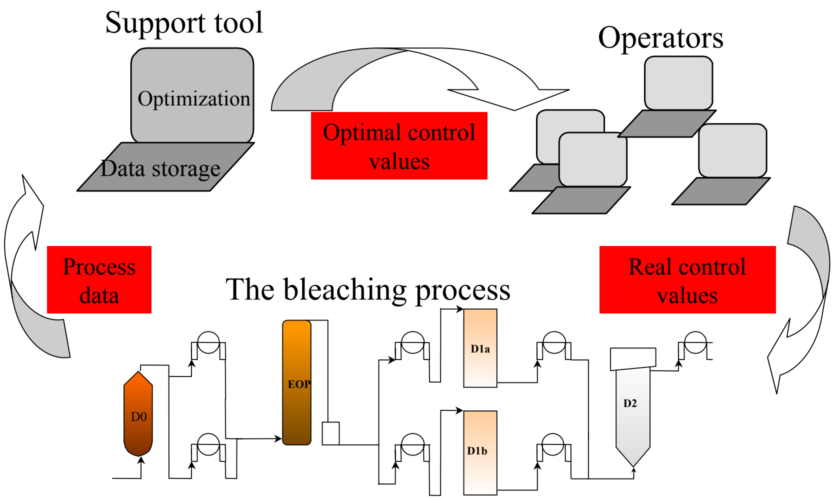
Time: 0 h
Brightness: 39.2

Time: 2.93 h
Brightness: 74.75

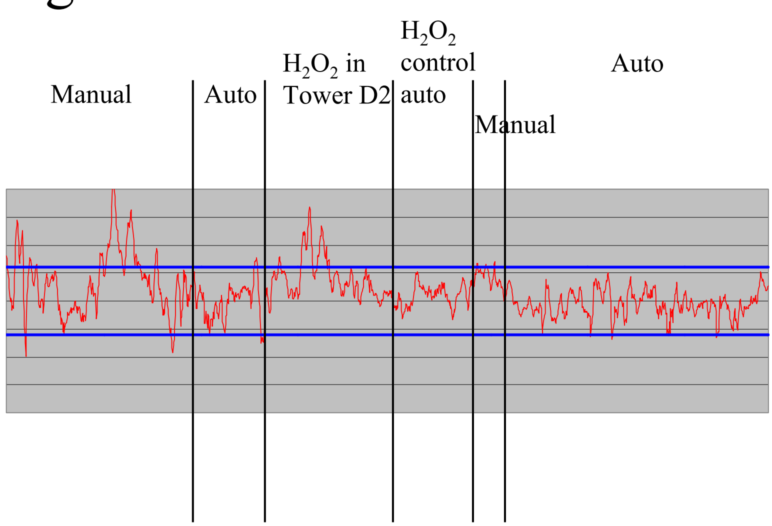
Time: 5.61 h
Brightness: 87.26

Time: 8.64 h
Brightness: 90.61

Support tool - information flow

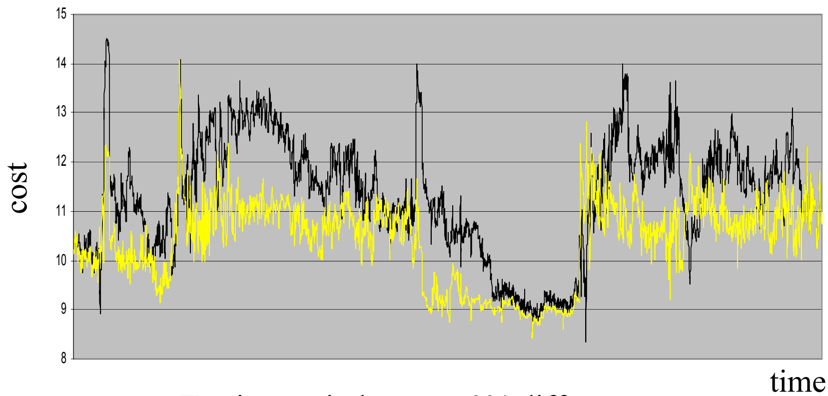


Brightness after Tower D2



A period of 16 months

Cost of manual run



Testing period gave > 9% difference

Annual €300,000 savings

Summary

Summary and future challenges

- Forest companies are developing supply chain modules
- Increasing usage of OR techniques in planning system
- Savings are typically in the order of 5-10%
- Important that OR skilled/educated persons are a part of the development
- Data collection can be hard and and faulty data is a potential problem
- Specialized models and methods required
  - Quick and robust solution methods