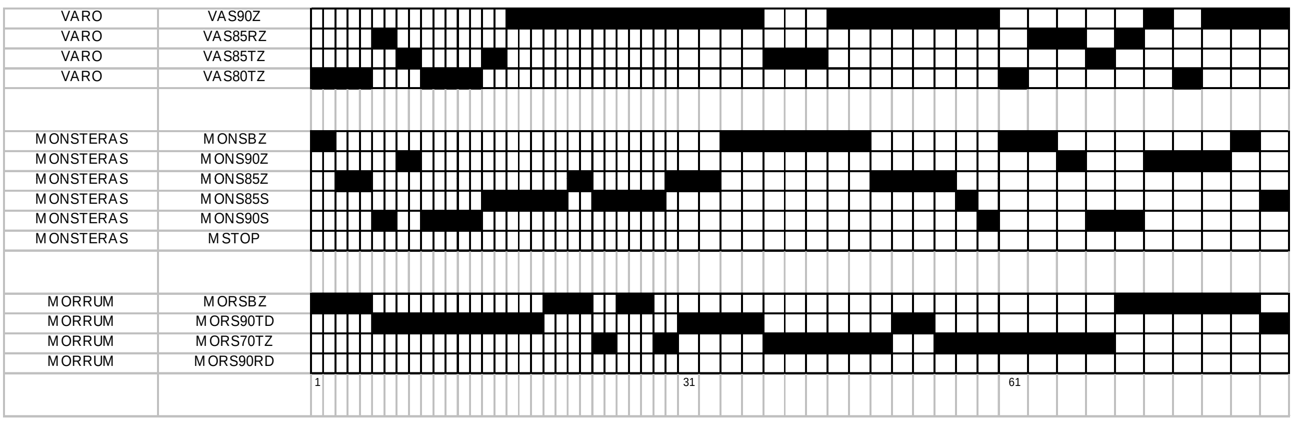
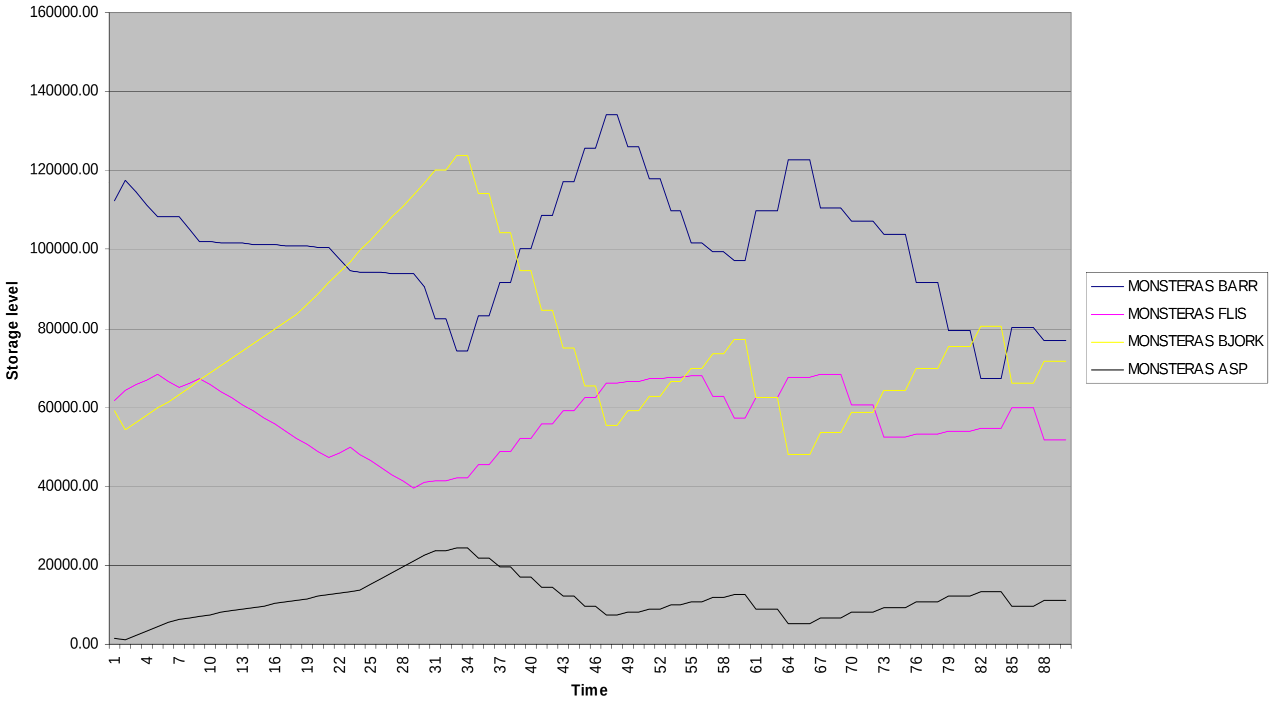
– 3 Swedish pulp mills
– Comparison with manual plan
– 10 forest districts producing 4 log types
– 15 products (specific recipes per pulp mill)
– 90 days planning giving 90 time periods (or aggregated 55 time periods)
– Model:
  • Master: 9,500 constraints; 31,800 variables+1,500 generated
  • Sub: Production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

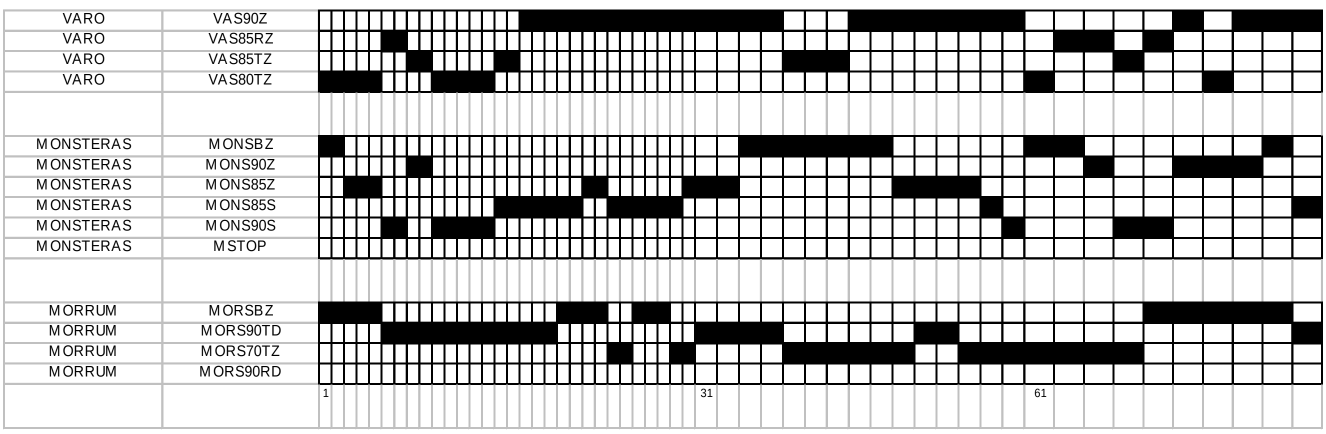
Production plans





Production plans

- Comparison with manual plans
  - Change over (manual 2.7 MSEK, opt 4,7 MSEK)



Total (manual 119.5 MSEK, opt 108.8 MSEK)

Tactical planning – Annual resource planning

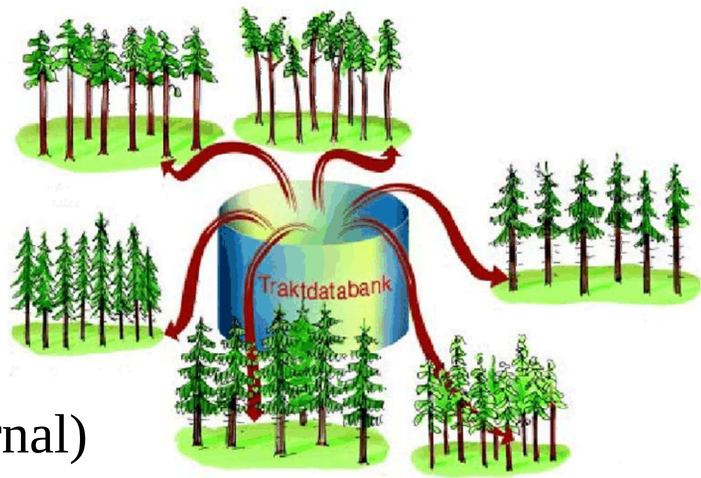
Case study at SCA

- 46 machines in 23 teams
- Harvesters: 22 small, 6 medium and 18 large
- Forwarders: 33 small, 10 medium and 8 large
- Each machine:
  - average capacity of 2400 hours
  - average cost 70-130 euros per hour
- 14 home bases
- 968 harvest areas with 8,971 hectares and 1,33 million cubic meters
- 4 seasons: winter 18 – weeks, spring – 9 weeks, summer – 16 weeks and autumn – 8 weeks

Harvest machines

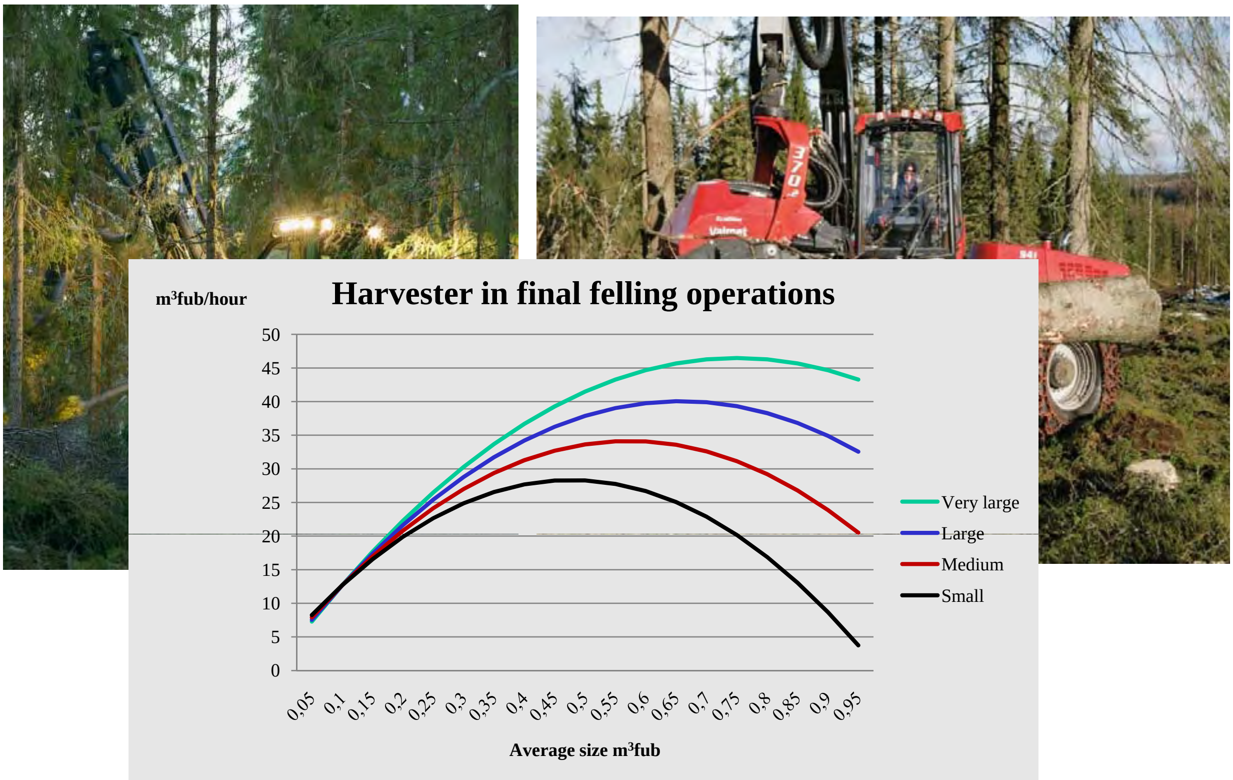
- Harvest team connection
- Machine type (harvester/ forwarder/ harwarder)
- Size (small, medium, large, very large)
- Efficiency (evaluated by the planner)
- Operating cost (SEK per hour)
- Available G_0 hours for thinning and final felling operations, respectively (combined for both)

Harvest areas

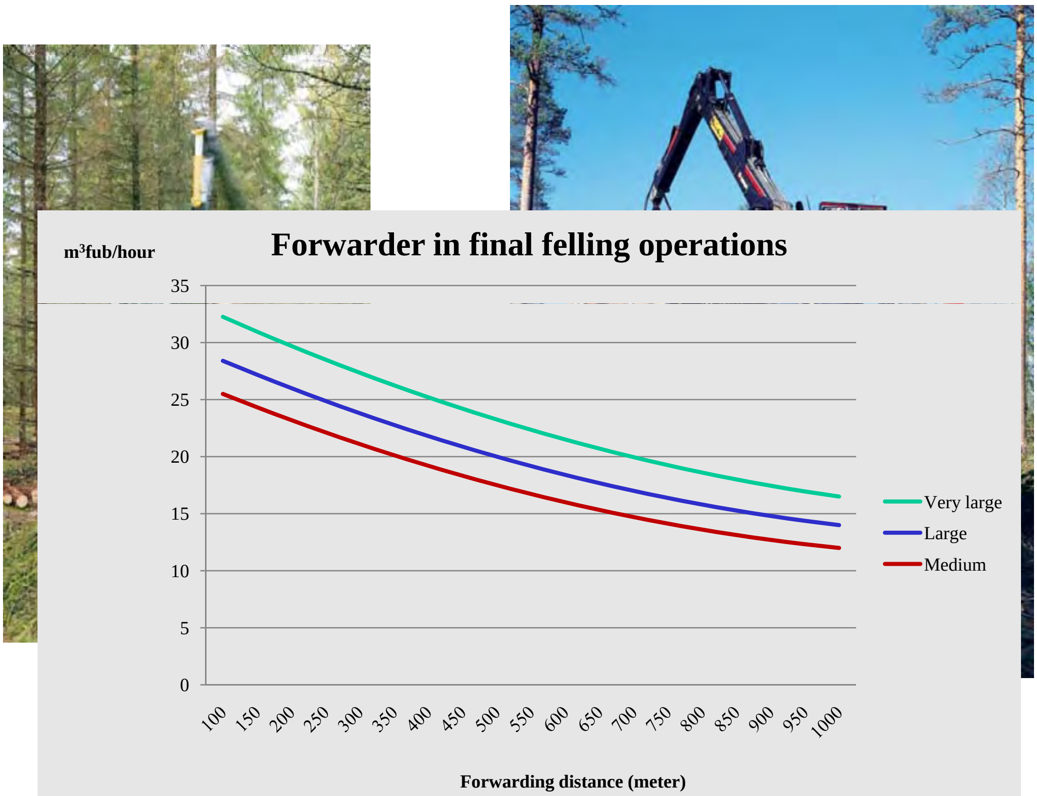


- GIS coordinates
- Ownership (own or external)
- Thinning or final felling operations
- Ground condition
- Area (square meter)
- Average size of a tree (cubic meter)
- Fowarding distance
- Volume
- Possible harvest periods (winter, spring, summer, autumn)

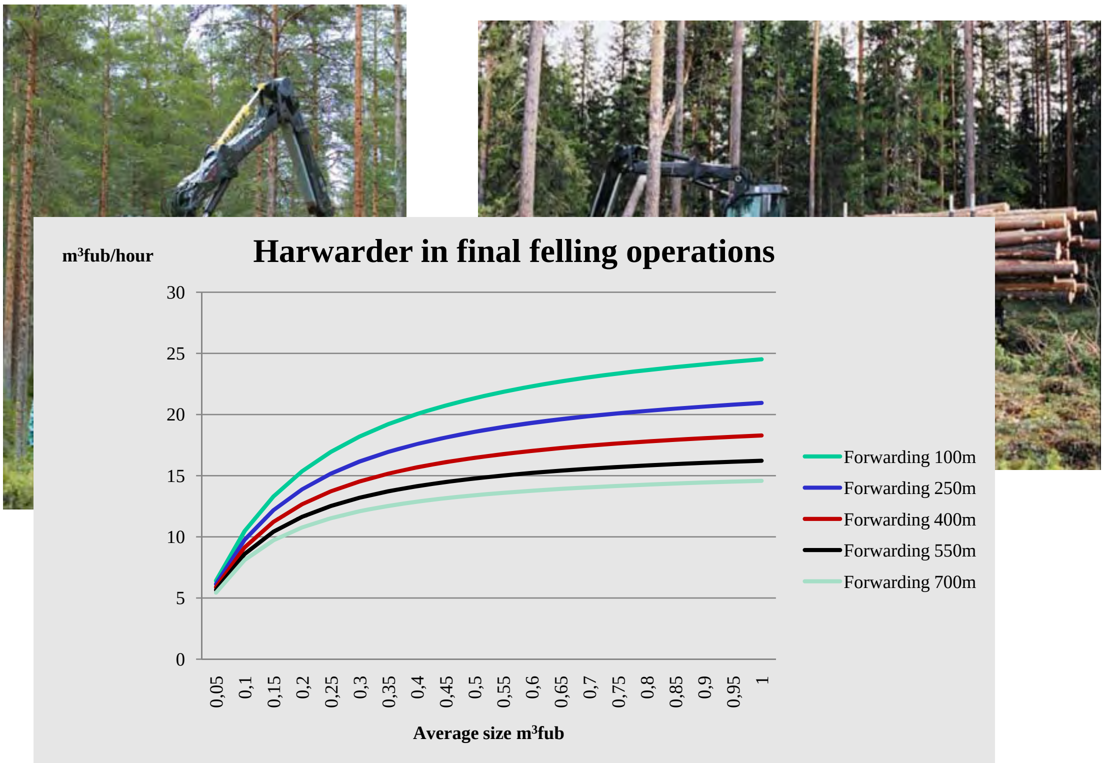
Performance functions harvesters



Performance functions - forwarders

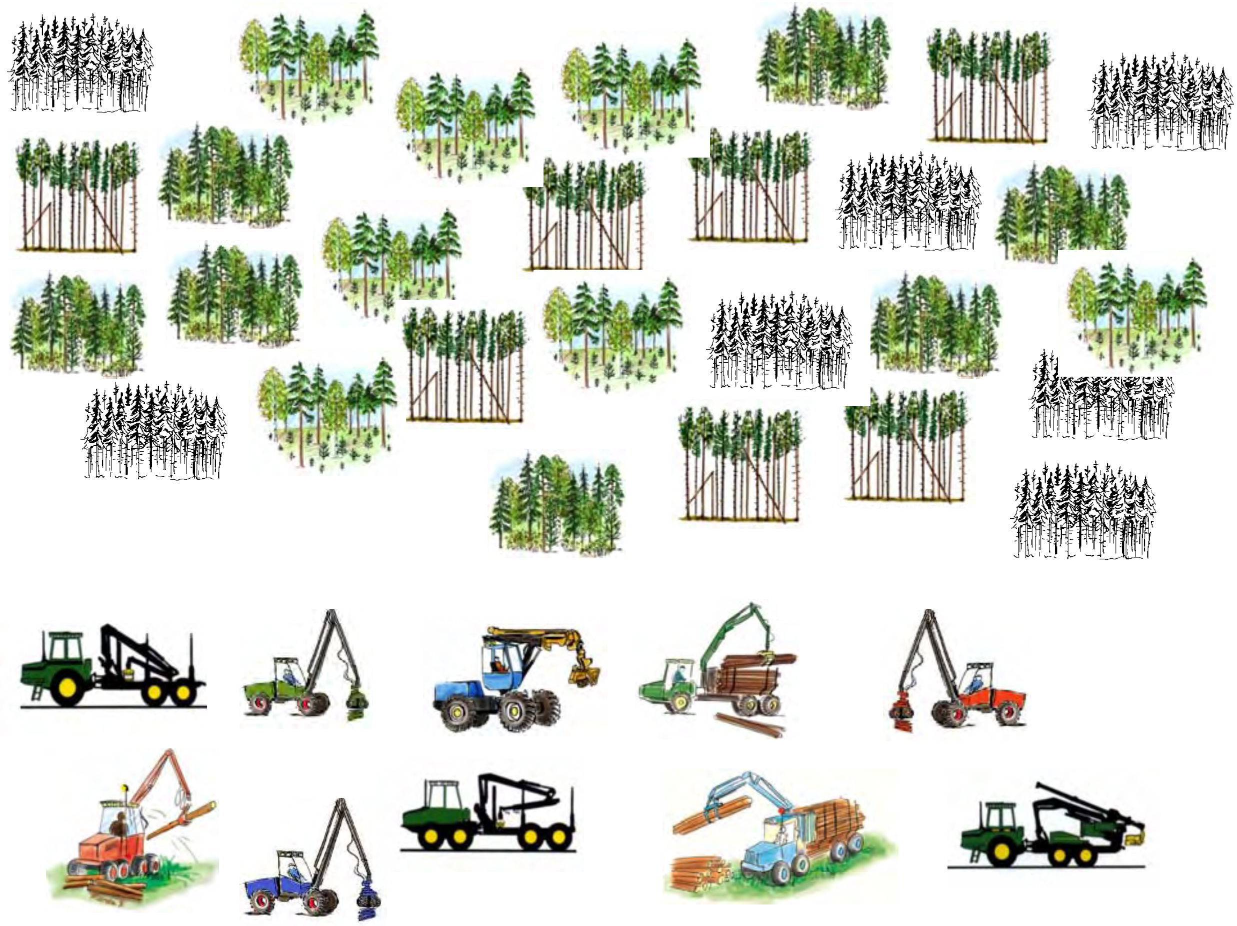


Performance functions - harwarder



Cost components

- Production cost
  - Harvesting cost
  - Forwarding cost
- Travel cost
  - Daily travel between home base and harvest area (based on km)
- Moving cost
  - Moving of equipment between harvest areas
  - Depending on distance:
    - Short: machine moves itself
    - Longer. machine put on a trailer



Optimization model - decisions

- Allocate machines to harvest areas
  - each harvest areas has two tasks: harvesting and forwarding
  - Note that each forwarder and harvester do only one task while a harwarders does two.
- Schedule and route the machines given their allocated harvest areas over the year
- Model: integrated location and routing problem

$$
\begin{aligned}
y_{mit} &= \begin{cases} 1, & \text{if machine } m \text{ is used in harvest area } i \text{ during season } t \\ 0, & \text{otherwise} \end{cases} \\
s_i &= \begin{cases} 1, & \text{if harvest area } i \text{ is in the pool} \\ 0, & \text{otherwise} \end{cases} \\
x_{mjk} &= \begin{cases} 1, & \text{if machine } m \text{ moves between harvest area } i \text{ and harvest area } j \\ 0, & \text{otherwise} \end{cases} \\
o_{mtt'} &= \text{overlap time used for machine } m \text{ between time period } t \text{ and } t'
\end{aligned}
$$

$$
\begin{aligned}
z_{production} &= \sum_{m\in M}\sum_{i\in I_m}\sum_{t\in T}(c^h_{mi}+c^f_{mi})y_{mit} \\
z_{traveling} &= \sum_{m\in M}\sum_{i\in I_m}\sum_{t\in T}h_{mi}y_{mit} \\
z_{moving} &= \sum_{m\in M}\sum_{i\in I_m}\sum_{j\in A}g_{mij}x_{mij} \\
z_{pool} &= \sum_{i\in I}\gamma v_i s_i
\end{aligned}
$$

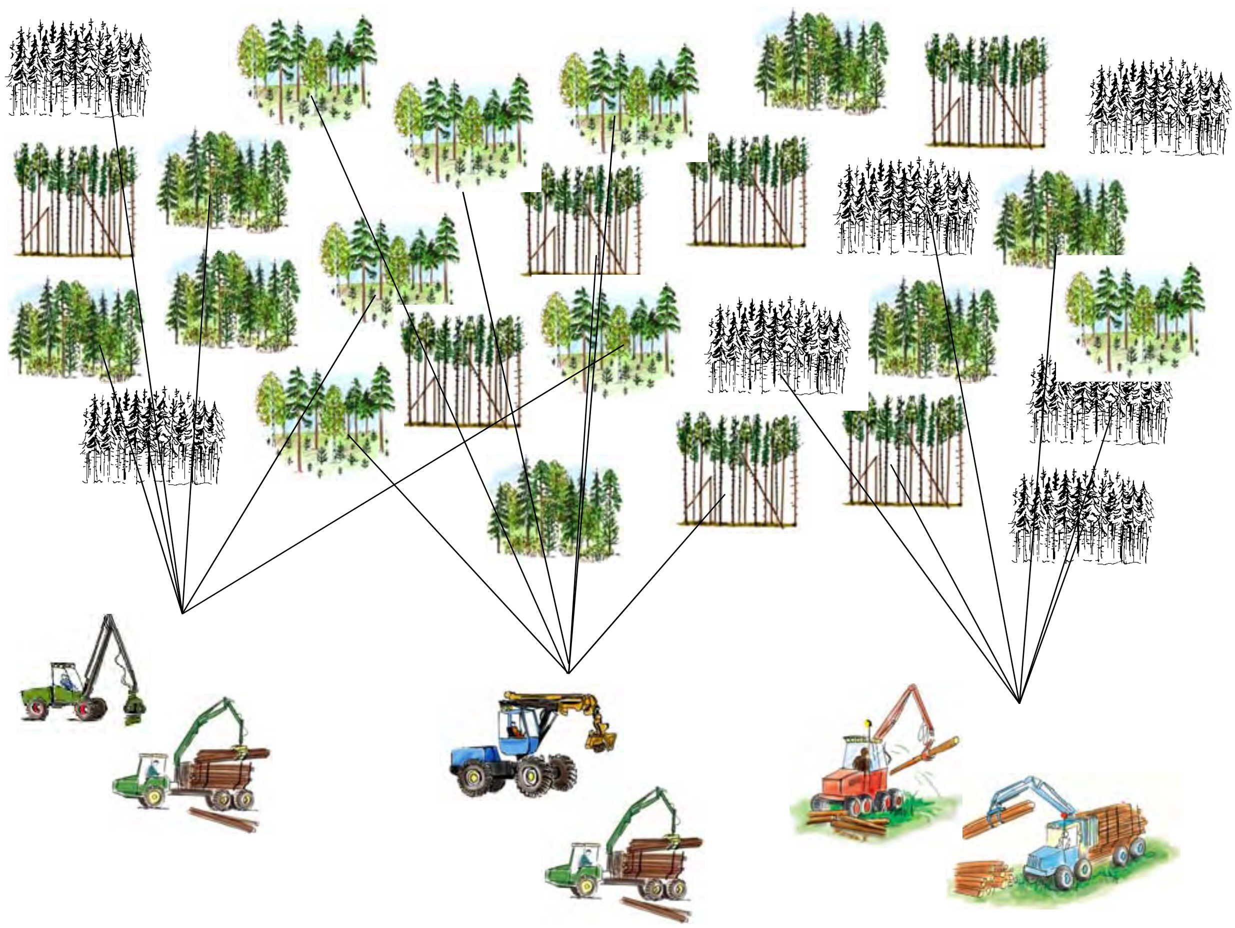
$$
\begin{aligned}
\min \quad z = \quad & z_{production}+z_{traveling}+z_{moving}+z_{pool} \\
\text{s.t.} \quad & \sum_{m\in M_h}\sum_{t\in T}y_{mit}+\sum_{m\in M_d}\sum_{t\in T}y_{mit}+s_i = 1, && i\in I && (1) \\
& \sum_{m\in M_f}\sum_{t\in T}y_{mit}+\sum_{m\in M_d}\sum_{t\in T}y_{mit}+s_i = 1, && i\in I && (2) \\
& \sum_{i\in I_m}(t^h_{mi}+t^f_{mi})y_{mit} \le t_{mt}, && m\in M, t\in T && (3) \\
& \sum_{t\in T}\Big(\sum_{i\in I_f}(t^h_{mi}+t^f_{mi})y_{mit}- \\
& a^w_m\textstyle\sum_{i\in I}(t^h_{mi}+t^f_{mi})y_{mit}\Big) \ge 0, && m\in M, w=t,f && (4) \\
& \sum_{m\in M}\sum_{t\in T}\sum_{i\in I_e}v_m s_m \le b^w, && w=t,f && (5) \\
& \sum_{m\in M}\sum_{i\in I_m}\sum_{j\in I_m}x_{mij} = \sum_{t\in T}y_{mjt}, && j\in I && (6) \\
& \sum_{m\in M}\sum_{i\in I_m}\sum_{j\in I_m}x_{mij} = \sum_{t\in T}y_{mit}, && i\in I && (7) \\
& \sum_{i\in S}\sum_{j\in S}x_{mij} \le |S|-1, && 2\le |S| \le |I|, m\in M && (8) \\
& y_{mit} \in \{0,1\}, && \forall m\in M, i\in I_m, t\in T && (9) \\
& x_{mij} \in \{0,1\}, && \forall m\in M, i,j\in I_m && (10) \\
& s_i \in \{0,1\}, && \forall i\in I && (11) \\
& y_{mit} = 0, && \forall m\in M, i\notin I_m, t\in T && (12)
\end{aligned}
$$

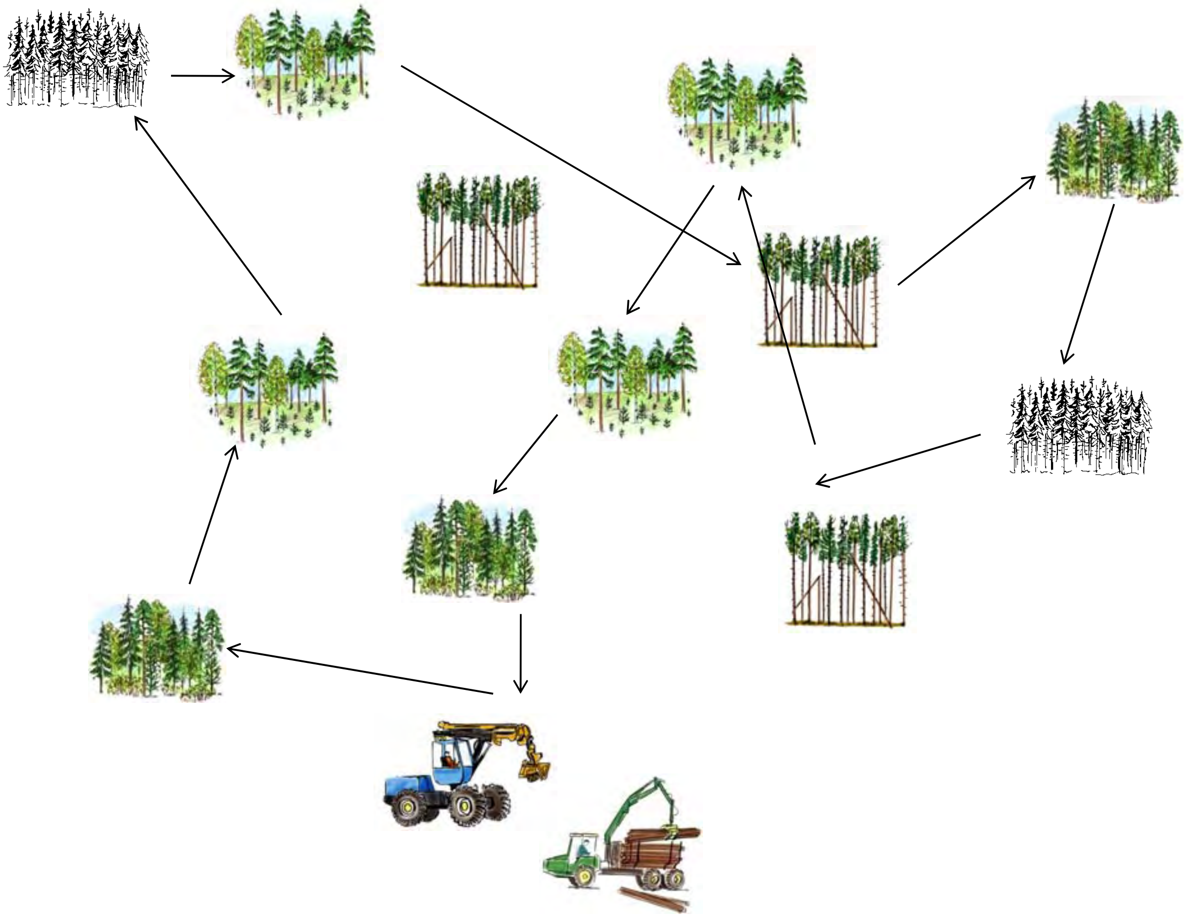
Optimization method

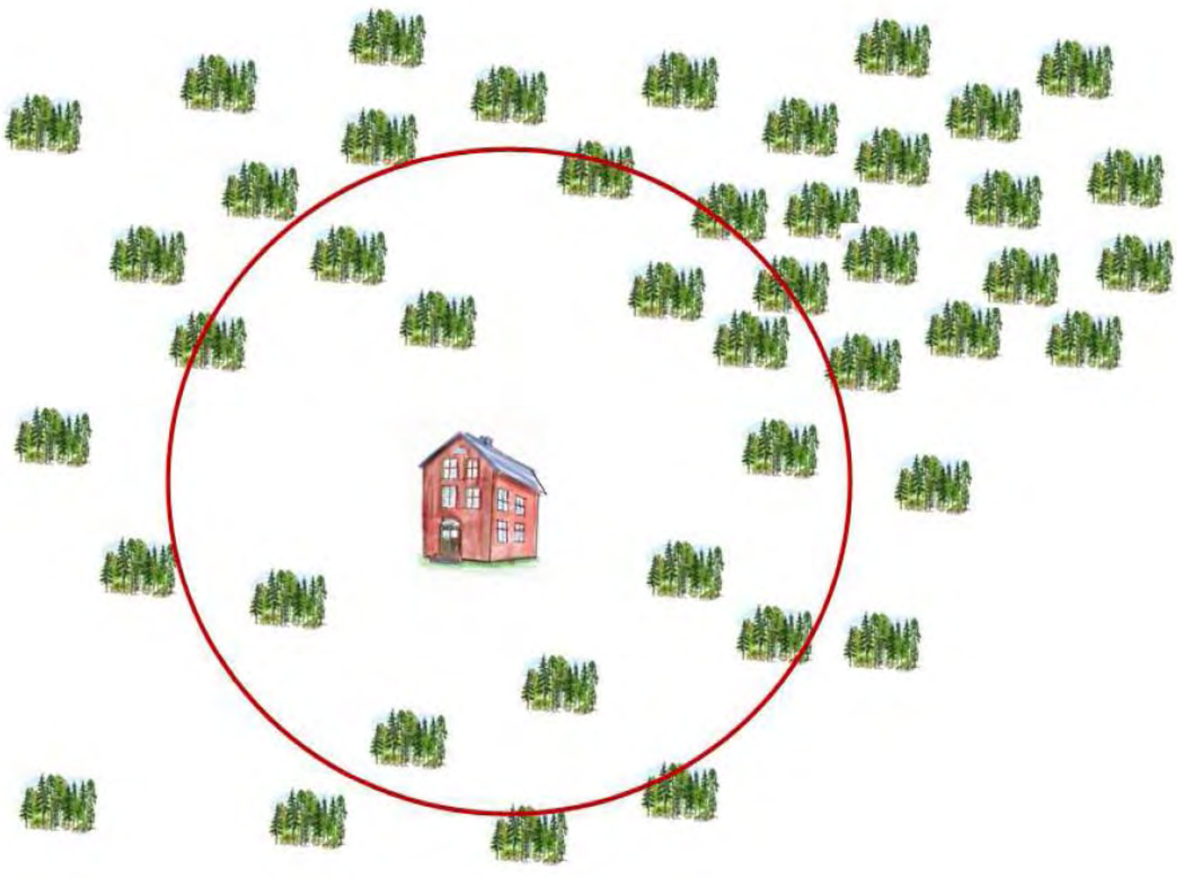
- We solve the problem in two phases:
- Phase 1: (Generalized assignment problem)
  - Decisions: Allocation of machines to harvest areas
  - Objective: production + traveling costs + pool cost + artifical to approximate moving cost
  - Constraints: all except scheduling

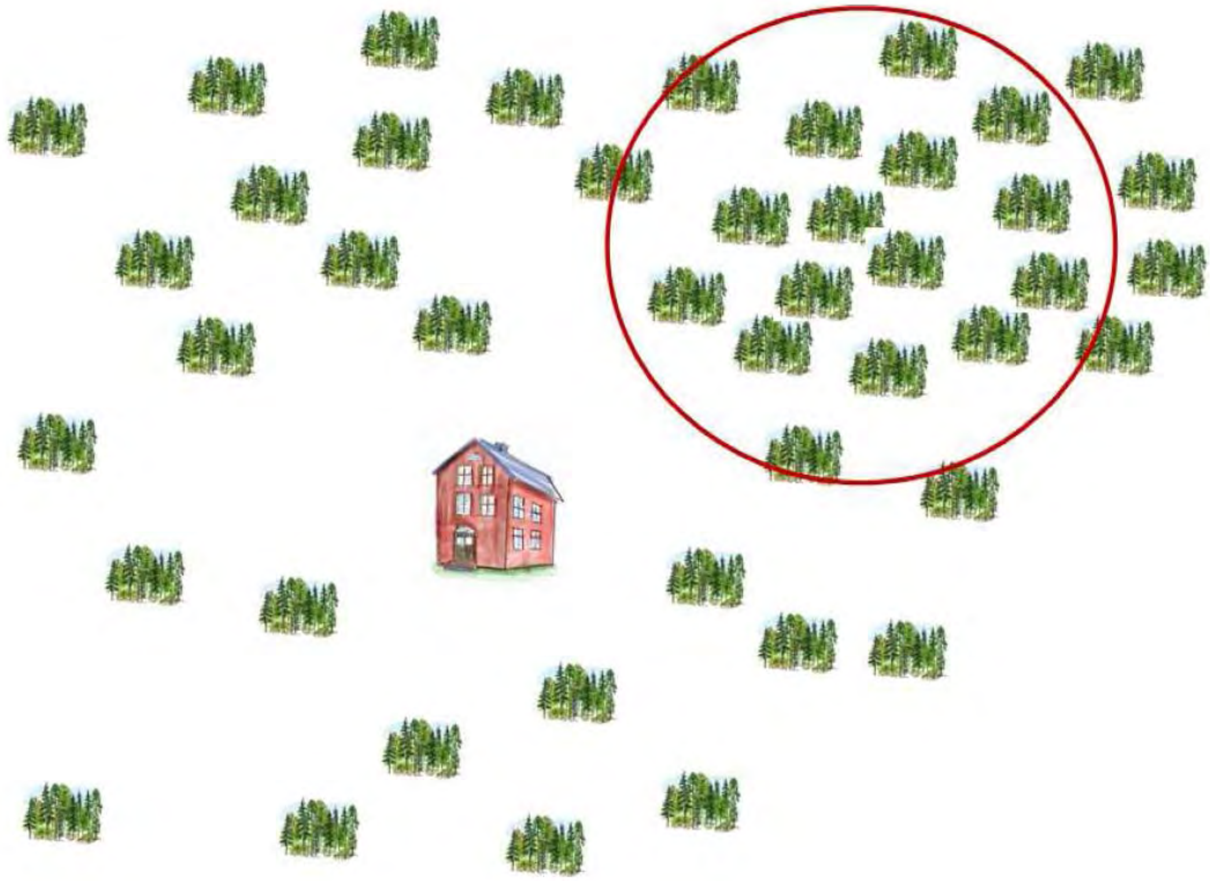
$$\sum_{i \in I_m} \alpha_1 * \alpha_2^{d[i,a]} y_{mit}$$

- Phase 2: (Traveling salesman problem)
  - Decisions: schedule the harvest areas allocated to each machine (take into accound seasons & overlap)
  - Objective: moving cost
  - Constraints: scheduling constraints, seasons & overlap



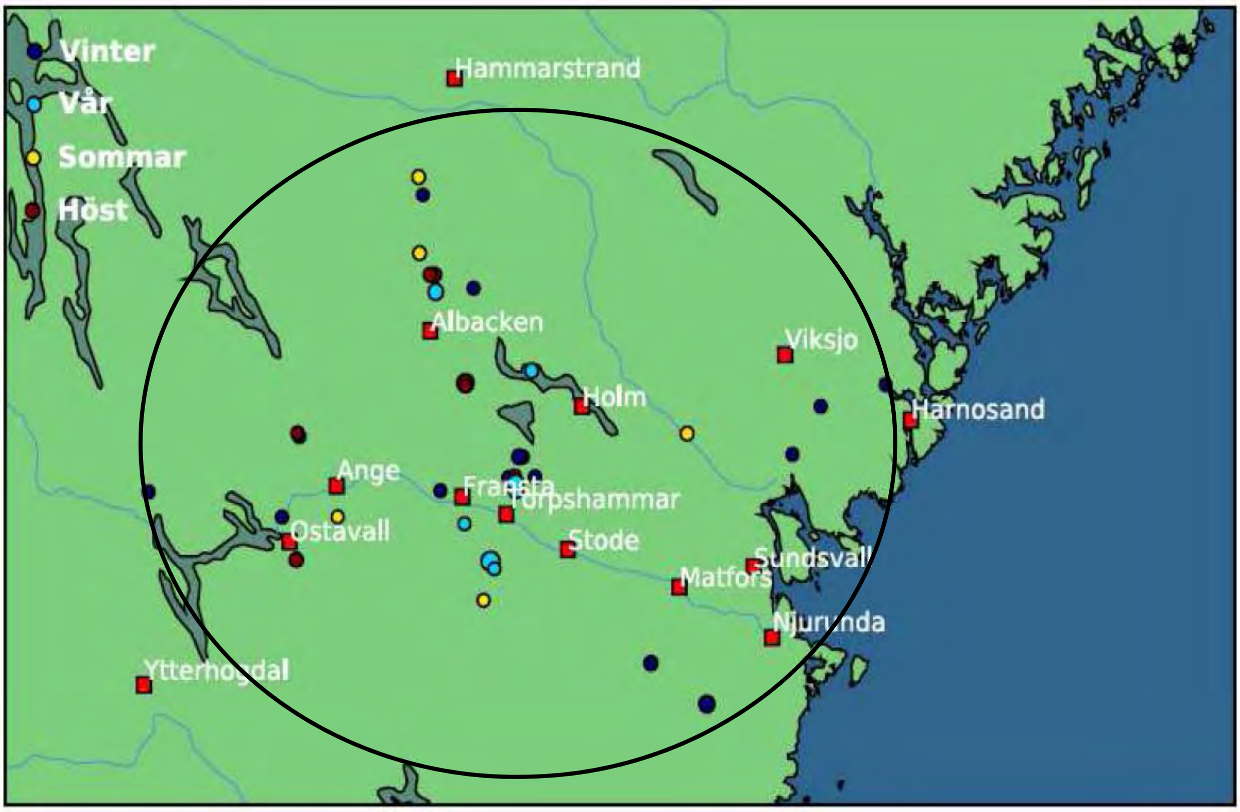


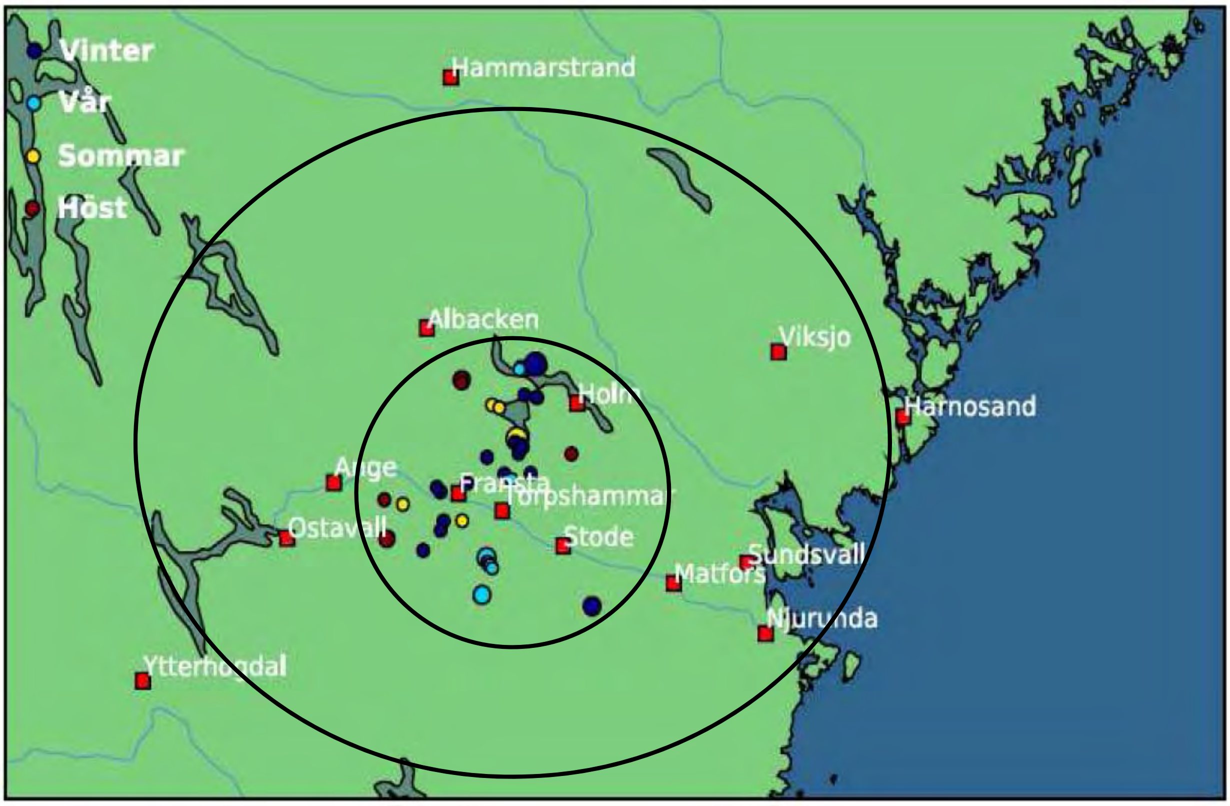




Implementaion and result generation

- Implementation using AMPL (with CPLEX) & Excel
- Input data:
  - one excel sheet
- Optimization
  - AMPL (model and developed method)
- Output result:
  - One Excel sheet with specified results
  - Aggregated result down to detailed
  - Maps with allocation and season scheduling

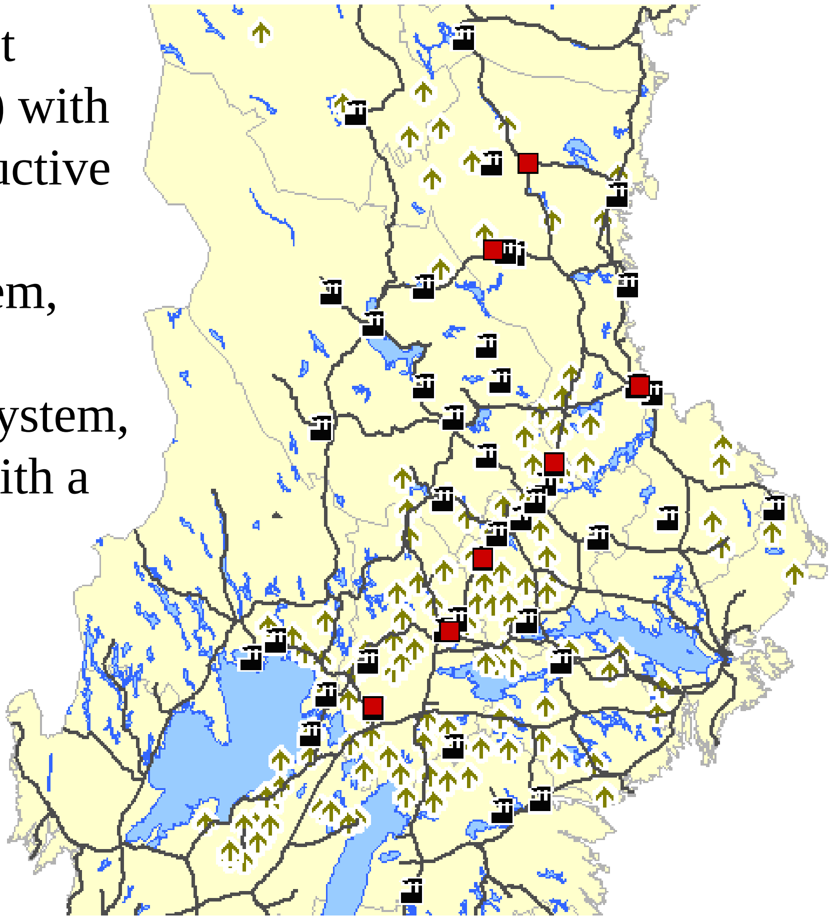

Vinter
Vår
Sommar
Höst
Hammarstrand
Albacken
Viksjo
Holm
Harnosand
Ange
Fransta
Torpshammar
Ostavall
Stode
Sundsvall
Matfors
Njurunda
Ytterhogdal


Vinter
Vår
Sommar
Höst
Hammarstrand
Albacken
Viksjo
Holm
Harnosand
Ange
Fransta
Torpshammar
Ostavall
Stode
Sundsvall
Matfors
Njurunda
Ytterhogdal

Supply chain design

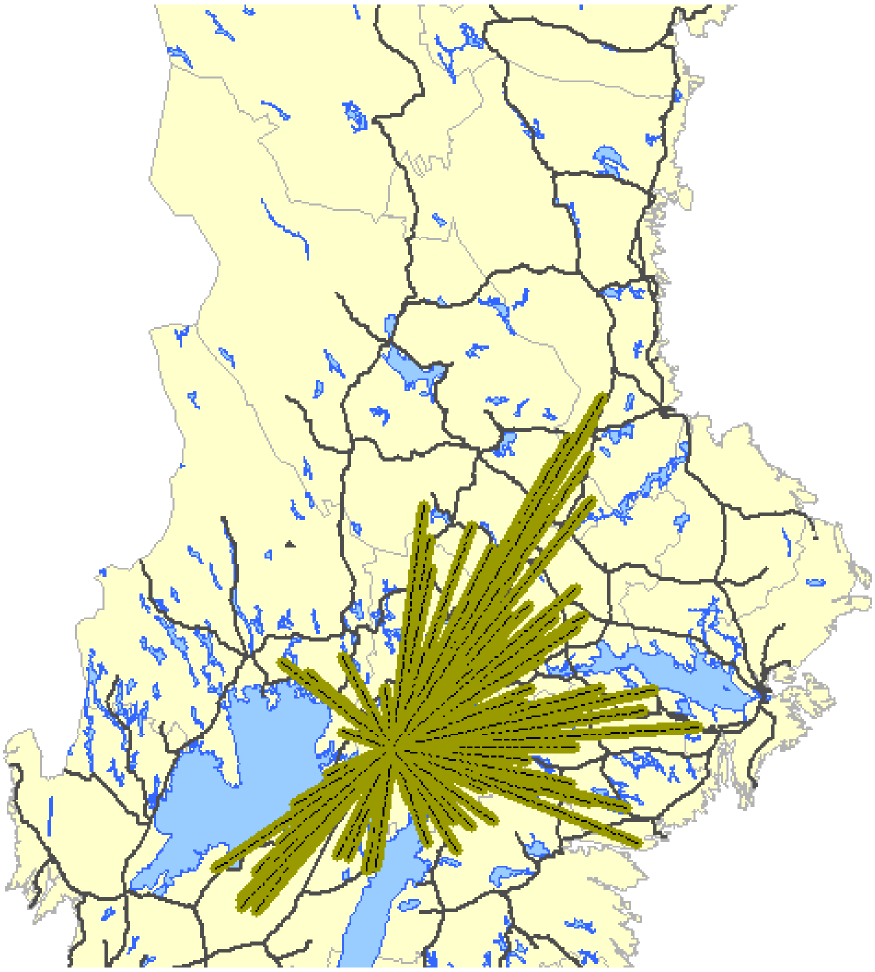
Train / terminal structure

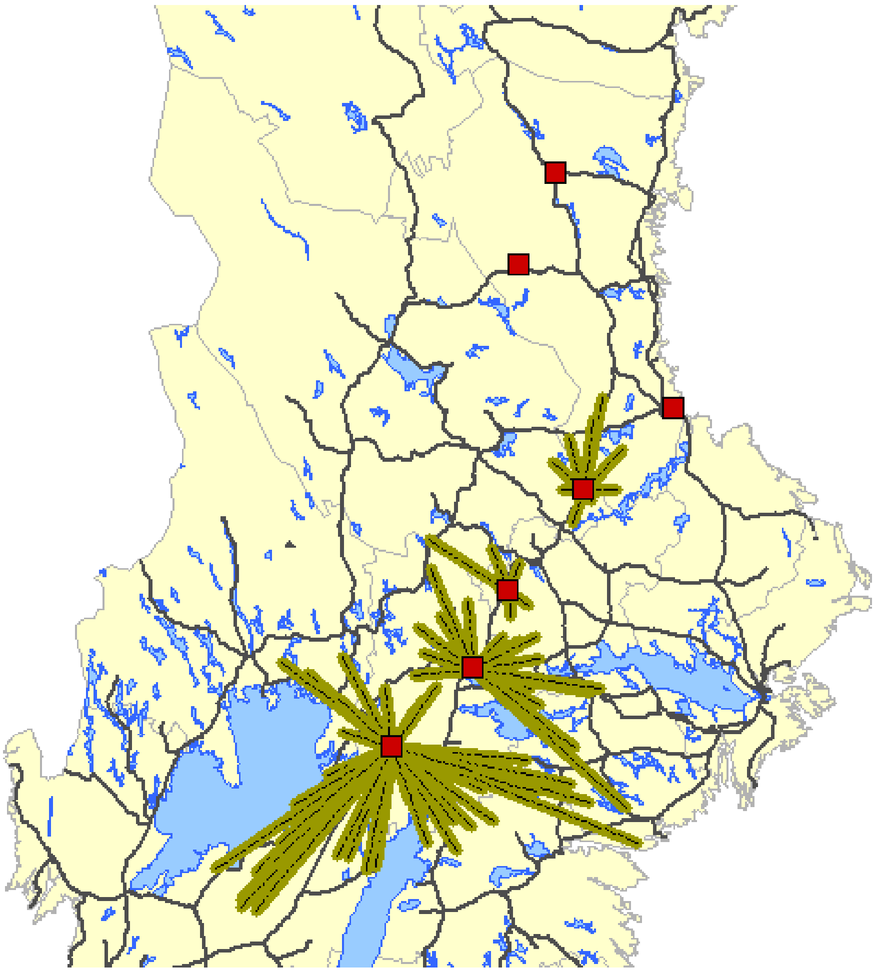
- Major Swedish forest company (Sveaskog) with 16% of overall productive forest area
- Using one train system, Trätåget
- Study to use a new system, Bergslagspendeln, with a number of potential terminals



Case study

- 1,500 supply points, 220 industrial demands,
- 5 train routes, 10 potential terminals,
- 12 products, 8 product groups, five scenarios.
- 3,000 constraints, 30 million variables
- Solution time 1 minute – several hours
- Truck transports reduced by 35% and overall energy 20%





Concluding remarks

Summary and future OR opportunities/ challenges

- Typical savings from optimization: 5-10%
- Specialized models and methods required
  - Important with ”real world” models and data
  - Quick and flexible/robust solution methods
- Forest industry is an area with open optimization problems
- Opportunities:
  - Robust models to meet uncertainties
  - New applications e.g. forest fuel supply chain
  - Consider faulty data in the planing process
  - Integrate several steps of the supply chain
  - Environmental considerations (CO_2, bio-diversity, recreational, ..)
  - Operations Research vital for ongoing industrial success

Articles

- D. Bredström, P. Jönsson and M. Rönnqvist, Annual planning of harvesting resources in the forest industry, *International Transactions in Operations Research,* Vol. 17, No. 2, 155-177, 2010.
- P. Flisberg, B. Liden and M. Rönnqvist, A hybrid method based on linear programming and tabu search for routing of logging trucks, *Computers & Operations Research,* Vol. 36, 1122-1144, 2009.
- S. D'Amours, M. Rönnqvist and A. Weintraub, Using Operational Research for supply chain planning in the forest product industry, *INFOR,* Vol. 46, No. 4, 47-64, 2008.
- G. Andersson, P. Flisberg, B. Liden and M. Rönnqvist, RuttOpt – A decision support system for routing of logging trucks, *Canadian Journal of Forest Research,* Vol. 38, 1784-1796, 2008.
- D. Carlsson and M. Rönnqvist, Backhauling in forest transportation – models, methods and practical usage, *Canadian Journal of Forest Research,* Vol. 37, 2612-2623, 2007.
- H. Gunnarsson, M. Rönnqvist and D. Carlsson, A combined terminal location and ship routing problem, *Journal of the Operational Research Society,* Vol. 57, 928-938, 2006.
- M. Forsberg, M. Frisk, and M. Rönnqvist, FlowOpt – a decision support tool for strategic and tactical transportation planning in forestry, *International Journal of Forest Engineering,* Vol. 16, No. 2, pp. 101-114, July 2005.
- D. Bredström, J. T. Lundgren, M. Rönnqvist, D. Carlsson and A. Mason, Supply chain optimization in the pulp mill industry – IP models, column generation and novel constraint branches, *European Journal of Operational Research,* Vol 156, pp 2-22, 2004.

- *Articles on cutting are not included due to confidentiality requirements from companies*