Integrating risk in the optimization of forest management at the stand and landscape levels

Approaches and examples

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Contents

- Stand level
  - Two approaches
  - Three examples: NewStand, RotStand, Rodal
  - Decision variables are continuous

- Forest level
  - Two approaches
  - Two examples: Fire & Wind
  - Decision variables are integers
  - Combinatorial optimization
Optimization at the stand level

- **Objective function** is maximized (minimized)
  - NPV, SEV
  - NPV–Penalty
  - Cost
  - Utility

- **Decision variables** are optimized
  - They can be controlled (decided)
  - They define the management schedule
Decision variables

One thinning: 3 decision variables
Optimize the combination of $T(\text{thin})$, $\Delta G$ ja $T(\text{clearfell})$

Basal area (G)

Age

$T(\text{thin})$

$T(\text{clearfell})$
Optimization at the stand level

Outcome (objective function) depends on
- Decision variables (controllable)
- Uncontrollable variables
  - Bring risk and uncertainty
  - Define State of Nature

Anticipatory or Adaptive optimization
- Adaptive produces a decision rule (like reservation price)
- Anticipatory suggests management which has “usually a reasonably good outcome”
Basic approach

- Optimization algorithm
- Decision variables
- Objective function
- Simulation software
1 Stochastic optimization with the scenario technique

Risk

Optimization

Decision variables

Simulation software

Expected value of objective function

Scenarios for uncontrollable variables

Risk and attitude towards risk

Optimization

Decision variables

Simulation software

Objective function

Skenarios
2 Deterministic (probabilistic) approach

- Bright and Price (2000)
- Calculate the probabilities of all possible outcomes
  - Burns in year 1, \( p_1 = p_f \) (\( p_f \) = annual fire probability)
  - Burns in year 2, \( p_2 = (1-p_f)p_f \)
  - Burns in year 3, \( p_3 = (1-p_f)^2p_f \)
  - Does not burn before rotation age, \( p_R = (1-p_f)^R \)
- Simulate a full rotation
- Calculate NPVs for different cases (burns year 1, ...)
- Calculate probability-weighted mean NPV

\[
NPV_{\text{first}} = \sum_{t=0}^{R-1} p_t \cdot NPV_t + p_R \cdot NPV_R
\]

\[
SEV = \left[ 1 - \left( \sum_{t=0}^{R-1} \frac{p_t}{(1+r)^t} + \frac{p_R}{(1+r)^R} \right) \right]
\]
1 Example: NewStand

Stand management optimization in Finland

Scenario technique

Stochastic scenarios generated for:

- **Regeneration result**: Multi-normal distribution of planted pine, natural pine, natural spruce, natural birch etc.
- **Timber prices**: Cross-correlated autoregressive random walk models
- **Tree growth**: Cross-correlated autoregressive random walk models
1 Example: NewStand

Pine management

- Plant when not enough natural seedlings
- No planting, no site preparation
- Only site preparation, no planting
- Planting, site preparation, optimize cuttings
- Current recommendation

NPV 3%, €/ha

-400  0  400  800  1200
2 Example: RotStand

- Stand management optimization in Finland and elsewhere
- Stand development deterministic
- Spread of heterobasidion stochastic
3 Example: Rodal

- Pine stand management optimization in Spain & Portugal
- Under the risk of fire
- Bright and Price method

![Graph showing rotation length vs. probability of fire]
Example: Rodal

If salvage rate depends on stand characteristics, results are more variable.

Safe time to grow trees
Optimization at the forest level

- **Stochastic optimization with the scenario technique**
  - Each treatment schedule simulated several times > expected value
  - When risk factors are non-spatial
  - Timber price, tree growth, regeneration

- **Risk factors are often spatial**
  - Wind damage
  - Fire damage
  - Diseases
  - Other approaches required
    - **Risk indices (approach 1)**
    - **Stochastic spatial optimization (approach 2)**
Risk indices (approach 1)

- Describe vulnerability
- Calculated for all treatment schedules of stands
- Mean risk index minimized in optimization

**Critical wind speed**
- Calculated for stand borders, depends on adjacent stand
- Wind speed at which trees start to fall down
- The lower, the more sensitive to wind damage

**Expected fire damage**

\[
y = -6.270 + 0.061 \cdot \text{Slope} + 2.333 \cdot \text{Pine} + 4.790 \cdot \left( \frac{S_d}{D_q + 0.01} \right) + e
\]

\[
y = \ln\left(\frac{P_{\text{dead}}}{(P_{\text{dead}} - 1)}\right)
\]
Wind risk example

Prevailing wind direction

This border has low critical wind speed
It is a vulnerable border

This border is not vulnerable
Wind risk example

- Critical wind speed converted to probability of wind throw
- Mean probability of wind throw minimized of maximized

Minimize MRI (MRI = 0.01)  Maximize MRI (MRI = 0.06)

Tone indicates tree height (black = 30 m; white = 0 m)
Wind risk example

- Minimization of height differences between adjacent stands is nearly equally good method.

Minimize MRI with a cutting target

Minimize height differences with a cutting target

Tone indicates tree height (black = 30 m)
Stochastic spatial optimization (approach 2)

Principle:
1. Produce a candidate plan (using heuristics)
2. Evaluate it using a stochastic spatial simulator (for fire spread, wind damage, disease spread). Use e.g. 1000 stochastic simulations
3. Return the simulation result to the optimization algorithm (e.g. mean probability to burn)
4. Make changes in the plan
5. Repeat steps 2–4 until convergence reached

Maybe the best method available
Problem: extremely slow, practically never used
Compromise method (Gonzalez & Pukkala)

- Fire loss index minimized
- Loss index = Fire probability x Fire damage
- Problem: Fire probability depends on entire landscape and on management -> not known

1. Use fire spread simulator (e.g. 1000 times with random ignitions) to calculate fire probability for different stands of the initial landscape
2. Optimize management (minimize mean fire loss index as one objective)
3. Use the resulting landscape and fire simulator to update fire probabilities
4. Repeat steps 2–3 until management and fire probabilities converge
Compromise method (Gonzalez & Pukkala)

Initial fire probability
\[ = f(\text{terrain, stand variables}) \]

Dark: high probability to burn

Ending fire probability if no management
Compromise method (Gonzalez & Pukkala)

Plan 1
Max net income

Plan 5 has a greatly reduced risk of fire damages

Plan 5
Max risk-adjusted income
Min mean fire loss index
Conclusions

- **Stand level**: stochastic optimization with the scenario technique the most promising
  - No need for simplifying assumptions

- **Forest level**:
  - Stochastic spatial optimization with continuous planning might be good
    - Plan developed as explained above
    - **If fire happens, the plan is updated (new plan developed)**
  - Heuristic optimization and stochastic spatial simulation need to be integrated
  - Computational requirements are high
  - Simplifications required
  - Much space for new research
Thank you!