An improved workflow to identify an optimal cable road layout for a large management unit

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An improved workflow to identify an optimal cable road layout for a large management unit

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Problem – Harvest planning in mountain forests

Klosters-Serneus (CH)

MIN harvesting cost

cable road

helicopter

truck road

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Snow processes must be accounted for when planning cable roads

bicriterion optimization problem
Management of mountain forests – the FOEN’s perspective

**climate policy and hazard prevention**
- regulation
- international environmental policy
- climate policy
- hazard prevention

**immission control**
- noise immission
- material effects water-, soil- and air quality

**protection and utilization of ecosystems**
- regulation
- international environmental policy
- resource efficiency
  - utilization of wood
  - ... recycling of municipal waste

**FOEN – Federal Office for the Environment**
Conceptual model for automatic harvest planning

Select
- harvesting system
- cable road
- landing

Minimize
- total harvesting cost
- strain snow processes

Constraint
- harvest all forest parcels
Mathematical formulation

\[
\begin{align*}
\text{net profit cable yarder} & \quad \text{installation cost cable yarder} & \quad \text{net profit helicopter} \\
\text{MIN} & \quad - \sum_{c}^{n_{ci}} \sum_{i} v_{ic} x_{ic} + \sum_{k} f_{k}^{c} y_{k} - \sum_{i} v_{i}^{H} x_{i}^{H} & \quad \text{cost [CHF]} \\
\text{MIN} & \quad \sum_{k} f_{k}^{SL} y_{k} & \quad \text{slope line [m]} \\
\text{Subject to} & \quad \sum_{c}^{n_{ci}} x_{ic} + x_{i}^{H} = 1 & \quad \text{harvest each forest parcel once} \\
& \quad \sum_{k \in M_{i}} y_{k} \geq x_{ic} & \quad \text{if forest parcel is harvested with system } c, \text{ a corresponding cable road } k \text{ covering } i \text{ must be installed} \\
& \quad y_{k} \leq y_{b} & \quad \text{select predecessor } b \text{ if cable road } k \text{ is selected} \\
& \quad y_{k} \leq t_{lm} & \quad \text{install tower at landing } lm \text{ if cable road } k \text{ is selected}
\end{align*}
\]

\[
\begin{align*}
x_{i}^{H} &= \begin{cases} 1, & \text{forest parcel } i \text{ harvested using helicopter} \\ 0, & \text{else} \end{cases} \\
x_{ic} &= \begin{cases} 1, & \text{forest parcel } i \text{ harvested using system } c \\ 0, & \text{else} \end{cases} \\
y_{k} &= \begin{cases} 1, & \text{select cable road } k \\ 0, & \text{else} \end{cases}
\end{align*}
\]

Bont, Leo Gallus. Spatially explicit optimization of forest harvest and transportation system layout under steep slope conditions. ETH Zurich (2012). http://dx.doi.org/10.3929/ethz-a-007558027
Current implementation

- **software**: Matlab, Gurobi
- **divide and conquer**: create sub-units
- **sub-units** calculated in a series
- manually-drawn set of objective weights
Approach for accelerating computation of harvesting plan

Accelerate workflow

Current workflow:
- desktop

New workflow:
- computing cluster

Reduce number of Pareto set-alternatives

Manually-drawn weights

Analytical selection of objective weights

Noninferior set estimation method NISE*

Basic principle of the NISE-method

«set of alternative solutions which characterize the Pareto frontier for a given error-level $T$»
Application to the Gotschna test area

**Forest**
- 227ha
- 1’350-1’800m
- Harvest restricted to timber stage ($\geq 300m^3/ha$)

**Forest road**
- 40t
- 3’700m

**Representation**
- 15x15m Raster
Sub-units subject to computation

Sub-units
- count: 7
- area: 22-81ha
- borders: forest road, cable car, arbitrary (terrain)

Potential cable roads
- count: 9,350-20,935
## Computational times

### EULER computing cluster at ETH

<table>
<thead>
<tr>
<th>SUB-UNIT</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td># forest parcels</td>
<td>1’561</td>
<td>1’497</td>
<td>3’066</td>
<td>3’009</td>
<td>1’515</td>
<td>2’670</td>
<td>2’569</td>
</tr>
<tr>
<td># potential cable roads</td>
<td>10’781</td>
<td>9’350</td>
<td>15’763</td>
<td>16’021</td>
<td>13’201</td>
<td>11’185</td>
<td>20’935</td>
</tr>
<tr>
<td># NISE</td>
<td>8</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Computational time [min]</td>
<td>5</td>
<td>2</td>
<td>77</td>
<td>230</td>
<td>49</td>
<td>10</td>
<td>19</td>
</tr>
</tbody>
</table>

Maximum allowable error: \( T = 0.05 \times \Psi_{12} \)

Distribute to cores
Pareto set – aggregated results

<table>
<thead>
<tr>
<th>solution</th>
<th>characterization</th>
<th>harvesting systems</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MIN harvesting cost</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MIX, pick Pareto-alternative closest to origin* (0,0)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MIN cable road in slope line-direction</td>
<td></td>
</tr>
</tbody>
</table>

* objective weights applied to sub-units differ ☝️ define merging rule
Pareto set - maps

- **MIN harvesting cost**
- **MIX, pick solution closest to origin (0,0)**
- **MIN cable road in slope line-direction**

**harvesting system**

- **helicopter**
- **only accessible via helicopter**
- **cable yarder**
- **cable skidder**
Conclusions / Outlook

Conclusions

[1] Parallelization limits overall computational time to sub-unit most difficult one to compute ($\pm 4h$)
[2] NISE-method facilitates characterization of Pareto set with small number of alternatives ($\pm 5$)

Outlook

[1] Design rules to plausibly match sub-unit alternatives computed with NISE-method
[2] Automate sub-unit delineation
[3] Design model for seamless delineation of cable roads across arbitrary borders
  ⇒ re-run model with partly fixed cable roads at extent of adjacent sub-units
Outlook

Work towards web-based implementation!

Minimize effort for...

... data acquisition
geodata is readily-available for entire Switzerland such as
DEM, road network, etc.

... software acquisition and maintenance
- cheap access to high-performing solvers
- no software prerequisites