Impact of yarding direction and silvicultural treatment on operation performance in whole tree cable yarding – an analysis based on plot level data

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Work studies in forestry

- Cycle level
- Shift level
- Plot level

„Collected“ datasets inhabitate human and machine-specific, unquantifiable effects

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Goal

Goal of this study was to determine the effect of yarding direction and silvicultural treatment on the productivity and other operation parameters.
Materials – data source

- Bavarian State Forests (Bayerische Staatsforsten) provided a rare dataset (one yarder and crew; 2008-2015)

- Corridor-wise (223) data from 55 harvesting operations conducted with a Koller K507 yarder with a four man yarding crew
Materials – data types

Data included:

- Time consumption (installation, productive working time, relocation, delay time)

- Operation and material parameters (yarded volume, number of trees, span length, yarding direction)

- Silvicultural treatment type
Materials – Silvicultural treatment types

- **Plus-tree thinning (TP)**
  - Two competitors of plus-tree removed, one-plus tree each 10 m

- **Slit cut thinning (TS)**
  - 30 m apart and 10 m x 20 m large areas are cut, 40 m distance between corridors

- **Group-cut regeneration (RG)**
  - Established regeneration is commenced through cuts, 35 x 35 m

- **Slit cut regeneration (RS)**
  - 35 m apart and 18 x 35 m large areas are cut, 80 m distance between corridors
Statistical analysis

- Statistical analysis was carried out in R:
  - Plausibility check
  - Descriptive statistics
  - Low number cases (yarding direction „horizontal“, silvicultural treatments „SH“) removed
  - Student‘s t-test (yarding direction) and Tukey honest significance differences test (silvicultural treatments)
  - Model for the time consumption of yarding was formulated through the application of regression analysis
  - Valid range of model was determined
Operation parameters

- Total of
  - 271,721 trees
  - 71,742 m³ volume

- Average of
  - 0.26 m³ per tree
  - 321.7 m³ per corridor
  - 1,218 trees per corridor
  - 330 m span length
  - 1.07 m³ m⁻¹ span volume
Operation parameters

- Total operations duration of 12,852.7 hours
- Delay share was 16.2%
## Results:
### Yarding direction impact

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Downhill Yarding</th>
<th>Uphill Yarding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity</td>
<td>m(^3) h PSH(_{15})^-1</td>
<td>9.6 ± 2.4(^a)</td>
<td>10.4 ± 2.2(^b)</td>
</tr>
<tr>
<td>Utilization</td>
<td>%</td>
<td>53.5 ± 10.7(^a)</td>
<td>58.6 ± 10.3(^b)</td>
</tr>
<tr>
<td>Productive time</td>
<td>h PSH(_{15})</td>
<td>30.5 ± 15.5(^a)</td>
<td>33.1 ± 17.3(^a)</td>
</tr>
<tr>
<td>Relocation time</td>
<td>h</td>
<td>1.5 ± 0.8(^a)</td>
<td>1.6 ± 0.9(^d)</td>
</tr>
<tr>
<td>Other time</td>
<td>h</td>
<td>7.4 ± 7.9(^a)</td>
<td>7.3 ± 7.6(^a)</td>
</tr>
<tr>
<td>Installation time</td>
<td>h</td>
<td>18.0 ± 6.8(^a)</td>
<td>15.0 ± 6.2(^b)</td>
</tr>
<tr>
<td>Total time</td>
<td>h</td>
<td>55.9 ± 24.6(^a)</td>
<td>56.4 ± 26.4(^a)</td>
</tr>
<tr>
<td>Span length</td>
<td>m</td>
<td>306.6 ± 134.4(^a)</td>
<td>341.7 ± 140.2(^a)</td>
</tr>
<tr>
<td>Total volume</td>
<td>m(^3)</td>
<td>280.3 ± 141.3(^a)</td>
<td>334.0 ± 162.9(^b)</td>
</tr>
<tr>
<td>Span volume</td>
<td>m(^3) m(^-1)</td>
<td>1.1 ± 0.5(^a)</td>
<td>1.0 ± 0.5(^a)</td>
</tr>
<tr>
<td>Tree volume</td>
<td>m(^3)</td>
<td>0.3 ± 0.1(^a)</td>
<td>0.3 ± 0.1(^a)</td>
</tr>
<tr>
<td>Total trees</td>
<td>n</td>
<td>1087 ± 596(^a)</td>
<td>1227 ± 703(^a)</td>
</tr>
</tbody>
</table>
## Results:
### Silvicultural treatment impact

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>TP</th>
<th>TS</th>
<th>RS</th>
<th>RG</th>
<th>UC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity</td>
<td>m³ h PSH₁₅⁻¹</td>
<td>7.6 ± 1.2</td>
<td>9.9 ± 2.1</td>
<td>10.8 ± 2.0</td>
<td>11.5 ± 2.8</td>
<td>7.5 ± 1.3</td>
</tr>
<tr>
<td>Utilization</td>
<td>%</td>
<td>56.3 ± 9.4</td>
<td>57.1 ± 10.0</td>
<td>54.8 ± 11.0</td>
<td>61.2 ± 9.1</td>
<td>71.1 ± 9.6</td>
</tr>
<tr>
<td>Productive time</td>
<td>h PSH₁₅</td>
<td>35.0 ± 14.6</td>
<td>32.7 ± 14.6</td>
<td>28.8 ± 16.3</td>
<td>38.1 ± 20.9</td>
<td>51.0 ± 20.2</td>
</tr>
<tr>
<td>Relocation time</td>
<td>h</td>
<td>1.3 ± 0.7</td>
<td>1.5 ± 0.9</td>
<td>1.6 ± 0.8</td>
<td>1.8 ± 1.2</td>
<td>1.9 ± 1.2</td>
</tr>
<tr>
<td>Other time</td>
<td>h</td>
<td>9.9 ± 9.5</td>
<td>7.4 ± 7.5</td>
<td>6.8 ± 6.3</td>
<td>9.0 ± 12.7</td>
<td>2.5 ± 1.4</td>
</tr>
<tr>
<td>Installation time</td>
<td>h</td>
<td>18.4 ± 6.4</td>
<td>16.5 ± 6.0</td>
<td>15.5 ± 6.7</td>
<td>15.1 ± 8.4</td>
<td>15.1 ± 3.3</td>
</tr>
<tr>
<td>Total time</td>
<td>h</td>
<td>67.5 ± 30.4</td>
<td>56.7 ± 21.7</td>
<td>51.4 ± 24.5</td>
<td>62.7 ± 36.3</td>
<td>70.2 ± 19.5</td>
</tr>
<tr>
<td>Span length</td>
<td>m</td>
<td>337.1 ± 162.0</td>
<td>353.3 ± 111.3</td>
<td>316.7 ± 143.2</td>
<td>263.9 ± 169.4</td>
<td>407.1 ± 105.8</td>
</tr>
<tr>
<td>Total volume</td>
<td>m³</td>
<td>258.1 ± 101.9</td>
<td>317.0 ± 138.8</td>
<td>301.4 ± 154.9</td>
<td>422.5 ± 241.3</td>
<td>373.6 ± 128.0</td>
</tr>
<tr>
<td>Span volume</td>
<td>m³ m⁻¹</td>
<td>0.83 ± 0.36</td>
<td>0.98 ± 0.39</td>
<td>1.03 ± 0.44</td>
<td>1.70 ± 0.61</td>
<td>0.91 ± 0.13</td>
</tr>
<tr>
<td>Tree volume</td>
<td>m³</td>
<td>0.25 ± 0.09</td>
<td>0.29 ± 0.09</td>
<td>0.32 ± 0.13</td>
<td>0.25 ± 0.11</td>
<td>0.19 ± 0.03</td>
</tr>
<tr>
<td>Total trees</td>
<td>n</td>
<td>1114 ± 538</td>
<td>1175 ± 505</td>
<td>1024 ± 613</td>
<td>1804 ± 1025</td>
<td>1986 ± 775</td>
</tr>
</tbody>
</table>
Results – Time consumption model

time consumption [h PSH_{25} m^{-3}] = a + b \cdot \text{tree volume}^{-0.2} [m^3] + c \cdot \text{yarding direction} + d \cdot \text{span length} + e \cdot \text{silvicultural treatment}

A: uphill yarding

B: downhill yarding
Conclusions

- **Yarding direction:**
  - Productivity is significantly higher in downhill yarding
  - Downhill yarding is significantly more laborious in terms of installation

- **Silvicultural treatment type:**
  - Productivity significantly increases if concentration effects are present
  - Treatment type does not affect installation time consumption

- **Study design:**
  - Single machine and crew data set is a rare and precious data source, but...
    - no data on slope inclination is available
    - no data on distribution of volumes along span length is available
    - no data on support number is available
Outlook

➢ Future research in cable yarding will have to deal with automatically captured machine data (like in fully mechanized harvesting systems), which can be used for similar, more detailed analyses.

➢ Upcoming H2020-project „Tech4Effect“ led by NIBIO/Norway, which BOKU is part of, will deal with this topic.
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