Skills development of mechanised softwood sawtimber cut-to-length harvester operators on the Highveld of South Africa

By Roland Marius Wenhold

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Use of mechanised systems

• Trend of mechanised systems (MS):
  – In 2007 fully-mechanised cut-to-length (CTL) systems were used 6.7% of all harvesting systems with motor-manual being predominant (67%)
  – In 2017 fully-mechanised cut-to-length systems were used 57% of all harvesting systems

• Reasons for using MS:
  – Ergonomics
  – Health and safety factors
  – Improved quality timber produced
Significance of this study

• Purchasing and implementing of mechanised systems are expensive and use high level technology:
  – Important to know HOW to select new (unexperienced) operators that will work at optimum levels
  – New operators need to work at optimum productive levels as quickly as possible
  – Important to evaluate WHEN these operators will be working at optimum levels
  – Important to know WHAT can be expected from these operators in terms of productivity levels, learning periods and loss of production costs involved

• Very few international studies deal with how long the learning curve of a beginner operator with no experience should be. Two studies were done by Thomas Purfust in Germany.
Objective of this study

- Describe and model productivity development learning curves of beginner harvester operators in both clear-felling and thinning operations.

- The following were sub-objectives:
  - Can psychometric tests give indication to a successful simulator operator?
  - How long should operators spend on simulator training before they move to the machine?
  - What are acceptable productivity ranges within particular operational and structural parameters?
  - What is an acceptable learning period for beginner harvester operators?
Introduction

- Study framework:
Methods

Initial operator selection

• Psychometric testing was used as a formal operator selection tool

• Operator were selected and scored (A = good, B = average or C = bad) based on the following psychometric abilities:
  – Two hand coordination
  – Time movement anticipation
  – Signal detection
  – Distance/speed and direction estimation
  – Ability to make non-verbal decisions

• The results were used to select operators that would move on to simulator training
Methods

Simulator training

- The following two repetitive simulator tests were completed by all initially selected operators:
  - Test 1: 3D (three-dimensional) simulator test
Methods

Simulator training

- Test 2: Felling of trees to the front towards an aiming point
Methods

**Simulator data collection**

- Time was recorded for each test
- Tests were completed three times per day (repetitive measure design)

<table>
<thead>
<tr>
<th>Test</th>
<th>Tests per day</th>
<th>Days for training</th>
<th>Number of operators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1 Thinning</td>
<td>3</td>
<td>19</td>
<td>4</td>
</tr>
<tr>
<td>Test 2 Thinning</td>
<td>3</td>
<td>14</td>
<td>4</td>
</tr>
<tr>
<td>Test 1 Clear-fell</td>
<td>3</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>Test 2 Clear-fell</td>
<td>3</td>
<td>7</td>
<td>4</td>
</tr>
</tbody>
</table>

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Methods

Simulator data analysis

- Each operator’s relative performance is calculated by dividing each observed test result (time per test) with the arithmetic mean of the population’s test results

\[
\text{Performance level} = - \left( \frac{P_o}{P_{\text{mean}}} \right) + 2
\]

- Therefore a performance level (PL) of 1 is the same as the population’s mean performance level (PPL).

- The evaluation of “time per test attempt” for Test 1 and Test 2 was used to describe the simulator learning curve.
Methods

In field harvesting

- Study Site:
Methods

In field harvesting

- Machine description:

  Ponsse Bear

  Ponsse Beaver

  Ponsse Buffalo

  Ponsse Elephant King
In field harvesting

**Data Collection:**
- Data collection period is 12 months
- Data is collected using SanForD (standard for forest data and communication) software as an automatic data collector on the on-board computer.
  - Produces .stm files that include all stem info such as DBH, height, volume UB, productivity, time stamps etc.
Discarding of outlier data

- All stem records that met at least one of the following criteria were removed:
  - A delay of longer than five minutes (300 seconds) was included in the cycle time
  - No harvested time stamp
  - Operator’s logging data not reaching 12 months of harvesting work
  - Thinning cycle time < 7 seconds
  - Thinning tree heights < 5 m; > 21 m
  - Thinning tree volumes < 0.1 m³; > 2.5 m³
  - Thinning tree DBHs < 14 cm; > 32 cm
  - Clear-fell cycle times < 25 seconds
  - Clear-fell tree heights < 10 m; > 30 m
  - Clear-fell tree volumes < 0.07 m³; > 2 m³
  - Clear-fell tree DBHs < 14 cm; > 50 cm
Methods

In field harvesting

• **Data analysis for learning curves:**
  – Two methods of learning curve calculations were developed for each operator

• **Learning curve I:**
  – Is used to demonstrate how an operator’s productivity increases over time as a function of tree volume
  – Gives the productivity ranges that an operator will work over different tree volumes

• **Learning curve II:**
  – To ensure that an increase or decrease in productivity is not an effect of an increase or decrease in tree size, each operator’s learning curve is graphically presented monthly as a function of productivity (vertical axes) over tree volume (horizontal axis).
Results (Selection)

- Initially 36 potential candidates participated in psychometric testing
- On completion of psychometric testing candidates scoring an overall performance of C and below were discarded
- Eight candidates finally selected and continued with training

<table>
<thead>
<tr>
<th>Operator number</th>
<th>Age</th>
<th>Normal situation. 1st interval</th>
<th>Crisis situation. 2nd interval</th>
<th>Recovery [from crisis]. 3rd interval.</th>
<th>Time Anticipation/MDT</th>
<th>Direction Anticipation/MDD</th>
<th>Speed/overall mean duration</th>
<th>Accuracy / overall % error duration</th>
<th>Cognitro Signal detection</th>
<th>Overall performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>2</td>
<td>22</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>3</td>
<td>24</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>4</td>
<td>30</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>5</td>
<td>28</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>6</td>
<td>19</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>7</td>
<td>21</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>C</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>8</td>
<td>26</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
</tbody>
</table>
Results

- Simulator training:
  - The end of the simulator learning phase is at the point where no significant increase in performance is made for at least two consecutive days.

Test 1 Learning curves for all thinning operators
Current effect: $F(18, 40)=6.3280$, $p=.00000$
Vertical bars denote 0.95 confidence intervals
### Results

- **Simulator training Test 1 (Thinning trainees):**

<table>
<thead>
<tr>
<th>Trainee</th>
<th>PL start</th>
<th>Days to reach PL = 1</th>
<th>PL end and days to reach the end</th>
<th>Increase PL</th>
<th>PL max</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>PL End</td>
<td>Days</td>
<td>Overall</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>6</td>
<td>1.3</td>
<td>16</td>
<td>130</td>
</tr>
<tr>
<td>2</td>
<td>0.19</td>
<td>9</td>
<td>1.25</td>
<td>16</td>
<td>557.89</td>
</tr>
<tr>
<td>3</td>
<td>0.79</td>
<td>4</td>
<td>1.3</td>
<td>7</td>
<td>64.56</td>
</tr>
<tr>
<td>4</td>
<td>0.19</td>
<td>12</td>
<td>1.1</td>
<td>16</td>
<td>478.95</td>
</tr>
<tr>
<td>Mean</td>
<td>0.29</td>
<td>7.75</td>
<td>1.24</td>
<td>13.75</td>
<td>307.85</td>
</tr>
<tr>
<td>Median</td>
<td>0.19</td>
<td>7.50</td>
<td>1.28</td>
<td>16.00</td>
<td>304.47</td>
</tr>
<tr>
<td>25% - quantile</td>
<td>0.05</td>
<td>4.50</td>
<td>1.14</td>
<td>9.25</td>
<td>80.92</td>
</tr>
<tr>
<td>75% - quantile</td>
<td>0.64</td>
<td>11.25</td>
<td>1.30</td>
<td>16.00</td>
<td>538.16</td>
</tr>
</tbody>
</table>
Results

In field harvesting

- In total 90,522 thinning and 62,118 clear-fell trees formed part of the study
- Descriptive statistics for the tree dimensions:

<table>
<thead>
<tr>
<th></th>
<th>Thinning</th>
<th></th>
<th>Clear-felling</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DBH (cm)</td>
<td>Height (m)</td>
<td>Tree volume (m³)</td>
<td>DBH (cm)</td>
</tr>
<tr>
<td>Mean</td>
<td>21.98</td>
<td>11.59</td>
<td>0.18</td>
<td>29.78</td>
</tr>
<tr>
<td>Median</td>
<td>20.7</td>
<td>11.63</td>
<td>0.14</td>
<td>29.8</td>
</tr>
<tr>
<td>Range (min–max)</td>
<td>11–49.8</td>
<td>7.2–24.8</td>
<td>0.02–1.69</td>
<td>14–48.4</td>
</tr>
</tbody>
</table>
Results

- **Operator productivity learning curve (I)**
  - Logarithmic regression models of productivity as a logarithmic function of tree volume for each month were developed to determine the learning curve for each operator.

<table>
<thead>
<tr>
<th>Work month:</th>
<th>Equation</th>
<th>Where:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$Y = 29.0459 + 26.2893 \times \log_{10}(x)$</td>
<td>$Y =$ Productivity ($m^3 \cdot PMH^{-1}$); and</td>
</tr>
<tr>
<td>2</td>
<td>$Y = 28.7097 + 19.053 \times \log_{10}(x)$</td>
<td>$X =$ Tree Volume ($m^3$)</td>
</tr>
<tr>
<td>3</td>
<td>$Y = 31.9778 + 17.5296 \times \log_{10}(x)$</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>$Y = 43.6702 + 25.0394 \times \log_{10}(x)$</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>$Y = 43.6615 + 25.5174 \times \log_{10}(x)$</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>$Y = 60.463 + 37.5663 \times \log_{10}(x)$</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>$Y = 52.7036 + 32.328 \times \log_{10}(x)$</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>$Y = 47.6553 + 28.2842 \times \log_{10}(x)$</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>$Y = 50.2486 + 29.731 \times \log_{10}(x)$</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>$Y = 45.1178 + 25.124 \times \log_{10}(x)$</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>$Y = 59.0114 + 38.6558 \times \log_{10}(x)$</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>$Y = 60.87 + 40.4789 \times \log_{10}(x)$</td>
<td></td>
</tr>
</tbody>
</table>
Results

Thinning Operator No 2 productivity learning curve (I)

Operator No. 2 learning curve for Productivity over tree volume per E5 workmonth.

Legend:
- Workmonth: 1
- Workmonth: 2
- Workmonth: 3
- Workmonth: 4
- Workmonth: 5
- Workmonth: 6
- Workmonth: 7
- Workmonth: 8
- Workmonth: 9
- Workmonth: 10
- Workmonth: 11
- Workmonth: 12
Results

- Thinning Operator No. 2 productivity leaning curve (I) summary

<table>
<thead>
<tr>
<th>Tree Volume (m³) class measured at</th>
<th>Start Productivity (m³·PMH⁻¹) (month 1)</th>
<th>End productivity (m³·PMH⁻¹) (month 12)</th>
<th>Increase in productivity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>10</td>
<td>35</td>
<td>250</td>
</tr>
<tr>
<td>0.6</td>
<td>25</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>1</td>
<td>28</td>
<td>60</td>
<td>114</td>
</tr>
<tr>
<td>1.4</td>
<td>30</td>
<td>68</td>
<td>127</td>
</tr>
<tr>
<td>1.8</td>
<td>36</td>
<td>70</td>
<td>94</td>
</tr>
<tr>
<td>Overall</td>
<td>25.8</td>
<td>56.6</td>
<td>119</td>
</tr>
</tbody>
</table>

- Can expect an overall increase in productivity of 119% over 12 months
Results

- Thinning operators performance learning curve (II)

![Graph showing the performance increase of thinning operators over time.](image-url)
Results

- Clear-fell operators performance learning curve (II)

![Graph showing clearfelling operators' relative performance increase over time at mean tree volume of 0.54m³](image)

- Operator No. 5: $R^2 = 0.928$
- Operator No. 7: $R^2 = 0.603$

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Discussion (Simulator training)

Can psychometric test results give indication to a successful simulator operator?

- Trainee No. 1 and 3 (Both A candidates) performed the best between the thinning operators:
  - In both tests, they managed to end with the highest PL
  - Psychometric tests gave some indication

- Trainee No. 7’s (A candidate) results were contradictory:
  - For test 1, he started and ended with the lowest PL and took the longest time to reach the end of his learning phase
  - For Test 2, however, he started and ended with the highest PL and took the shortest time to reach the end of his learning phase
  - Psychometric tests did not give any indication of this

- The same conclusion is made for trainee No. 8 (A candidate), who did the best in Test 1 and the worst in Test 2
How long should operators spend on simulator training before they move to the machine or next test?

- **Average thinning trainee**
  - The learning curve would end after 12 days (36 tests)
  - Start PL = 0.33 relative to the PPL of 1
  - Exceed the PPL in seven days
  - 23% per day increase (total = 293%)

- **Clear-fell trainees**
  - The learning curve would end after six days (18 tests)
  - Start PL = 0.49 relative to the PPL of 1
  - Exceed the PPL in four days
  - 40% per day increase (total = 245%)
Discussion

What are acceptable productivity ranges at mean tree volume within particular operational and structural parameters?

- Thinning operators
  - Mean tree volume = 0.18 m³
  - Month 1 productivity = 13.71 m³·PMH⁻¹
  - Month 12 productivity = 38.96 m³·PMH⁻¹
  - Mean productivity = of 28.8 m³·PMH⁻¹

- Clear-fell operators
  - Mean tree volume = 0.54 m³
  - Month 1 productivity = 27.5 m³·PMH⁻¹
  - Month 12 productivity = 43.75 m³·PMH⁻¹
  - Mean productivity = of 41.9 m³·PMH⁻¹
Discussion

What is an acceptable learning period for beginner harvester operators?

- Thinning operators
  - End of the learning period = between 6 and 12 month
  - Mean = 9 months
  - Average increase in performance = 218%

- Clear-fell operators
  - End of the learning period = 5 and 8 month
  - Average increase in performance = 104%

- Of the six harvester operator that revealed a learning curve, three operators more than doubled their performance

- These differences could be a result of different operator work techniques (Alam et al., 2014) or levels of motivation and human abilities (Purfürst & Erler, 2011).
Conclusion

- As per the objectives we can;
  - See how long simulator training should be
  - Know the theoretical acceptable learning curve for harvester operators

- We have done one of the first ‘green fields’ harvester studies in the country
- We have a sound understanding of machine and operator interaction in terms of productivity on a vast range of tree sizes over time
- We have taken the first steps in dealing and exploring ‘big data’ harvester data for the purposes of this work but also knock on studies
Conclusion

• Future studies should:
  – compare beginner operators who obtained good psychometric test results with those who obtained bad psychometric test results to identify if the selection process is of any value
  – broadened to larger sample sizes and multiple machine types over different study sites.
Thank you.

Questions?
## Results

- **Operator productivity learning curve (I)**
  - Thinning operators productivity

<table>
<thead>
<tr>
<th>Tree volume</th>
<th>Productivity range</th>
<th>Start Productivity (m$^3$·PMH$^{-1}$) (month 1)</th>
<th>End productivity (m$^3$·PMH$^{-1}$) (month 12)</th>
<th>Start Productivity (m$^3$·PMH$^{-1}$) (month 1)</th>
<th>End productivity (m$^3$·PMH$^{-1}$) (month 12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree volume</td>
<td>Operator No 1</td>
<td>16</td>
<td>40</td>
<td>25</td>
<td>84</td>
</tr>
<tr>
<td>Tree volume</td>
<td>Operator No 2</td>
<td>10</td>
<td>35</td>
<td>30</td>
<td>68</td>
</tr>
<tr>
<td>Tree volume</td>
<td>Operator No 3</td>
<td>20</td>
<td>50</td>
<td>50</td>
<td>96</td>
</tr>
<tr>
<td>Tree volume</td>
<td>Operator No 4</td>
<td>10</td>
<td>32</td>
<td>34</td>
<td>72</td>
</tr>
<tr>
<td>Tree volume</td>
<td>Operator No 5</td>
<td>8</td>
<td>20</td>
<td>24</td>
<td>76</td>
</tr>
<tr>
<td>Tree volume</td>
<td>Operator No 7</td>
<td>15</td>
<td>24</td>
<td>64</td>
<td>85</td>
</tr>
</tbody>
</table>

- Clear-fell operators
## Discussion

- **Effect of operator selection on simulator test results**
  - Assumed that trainees with good psychometric test results would have good simulator performance test results
  - True for thinning operators
  - False for clear-felling operators

<table>
<thead>
<tr>
<th>Trainee</th>
<th>Overall Psychometric result</th>
<th>Simulator test results</th>
<th>Test1</th>
<th>Test2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Start PL</td>
<td>End PL</td>
</tr>
<tr>
<td>1</td>
<td>A</td>
<td></td>
<td>0</td>
<td>1.3</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td></td>
<td>0.19</td>
<td>1.25</td>
</tr>
<tr>
<td>3</td>
<td>A</td>
<td></td>
<td>0.79</td>
<td>1.3</td>
</tr>
<tr>
<td>4</td>
<td>B</td>
<td></td>
<td>0.19</td>
<td>1.1</td>
</tr>
<tr>
<td>5</td>
<td>A</td>
<td></td>
<td>0.5</td>
<td>1.35</td>
</tr>
<tr>
<td>6</td>
<td>B</td>
<td></td>
<td>0.65</td>
<td>1.2</td>
</tr>
<tr>
<td>7</td>
<td>A</td>
<td></td>
<td>0.4</td>
<td>1.2</td>
</tr>
<tr>
<td>8</td>
<td>A</td>
<td></td>
<td>0.6</td>
<td>1.35</td>
</tr>
</tbody>
</table>