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

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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.

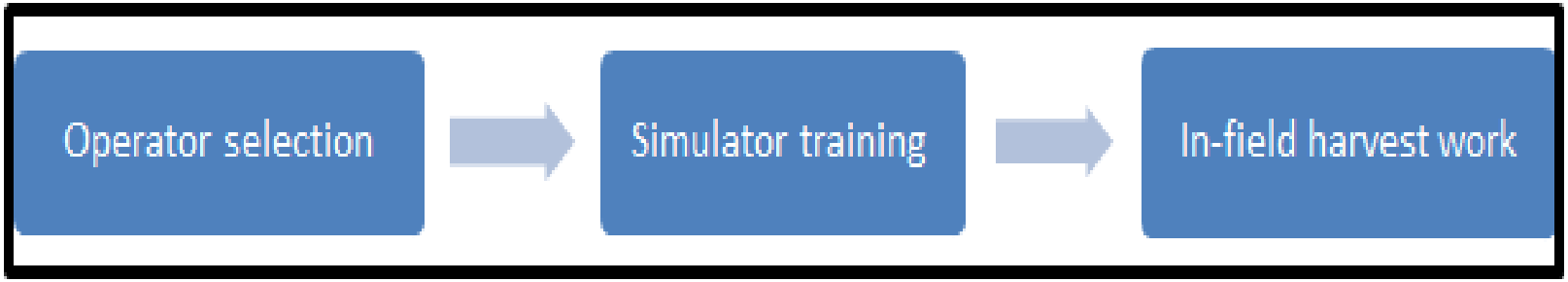
Objective of this study

- 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

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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

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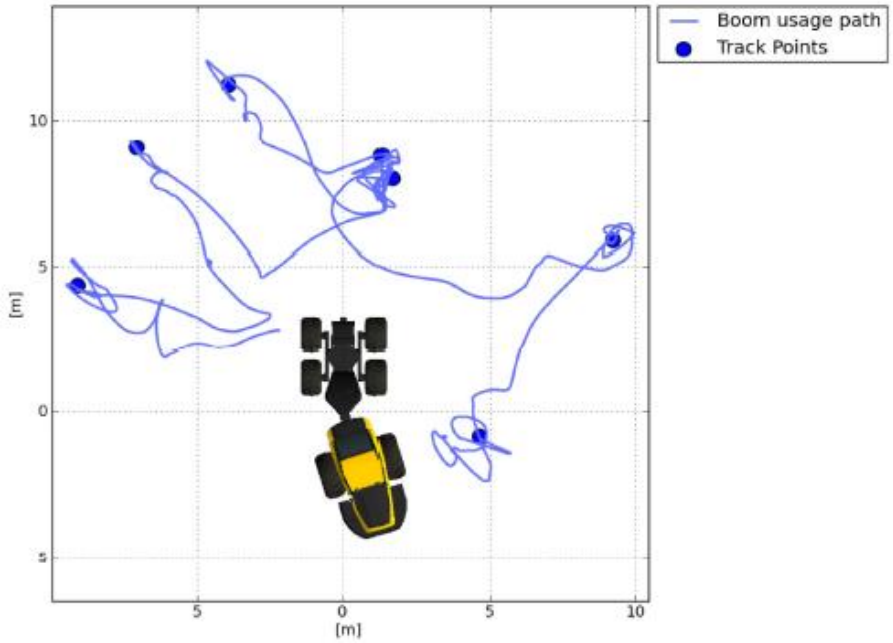
Simulator training

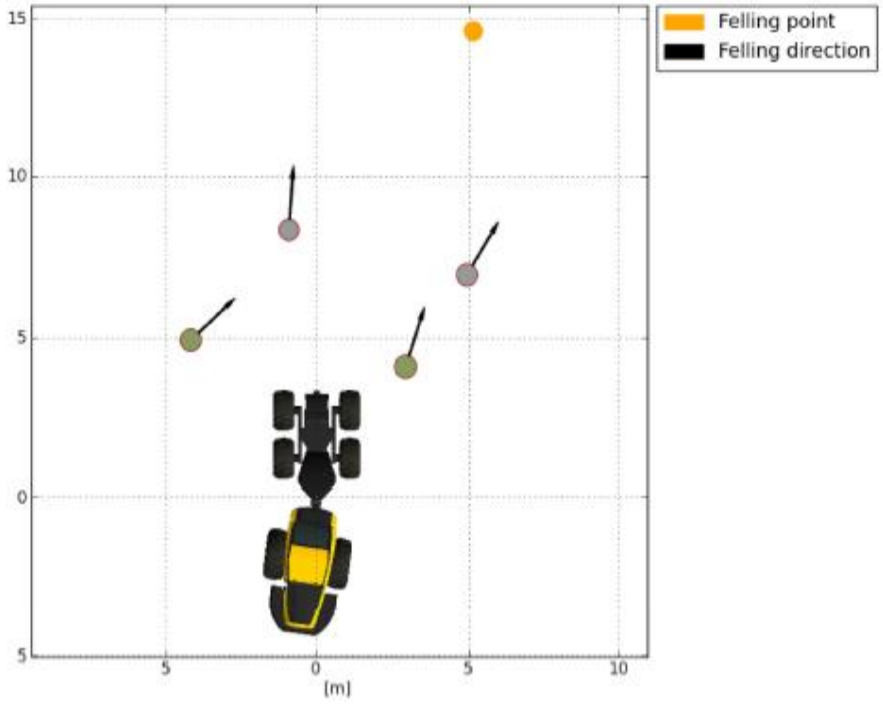
- The following two repetitive simulator tests were completed by all initially selected operators:
  - Test 1: 3D (three-dimensional) simulator test



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)

Test	Tests per day	Days for training	Number of operators
Test 1 Thinning	3	19	4
Test 2 Thinning	3	14	4
Test 1 Clear-fell	3	9	4
Test 2 Clear-fell	3	7	4

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

$$Performance\ level = -\left(\frac{Po}{Pmean}\right) + 2$$

- 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

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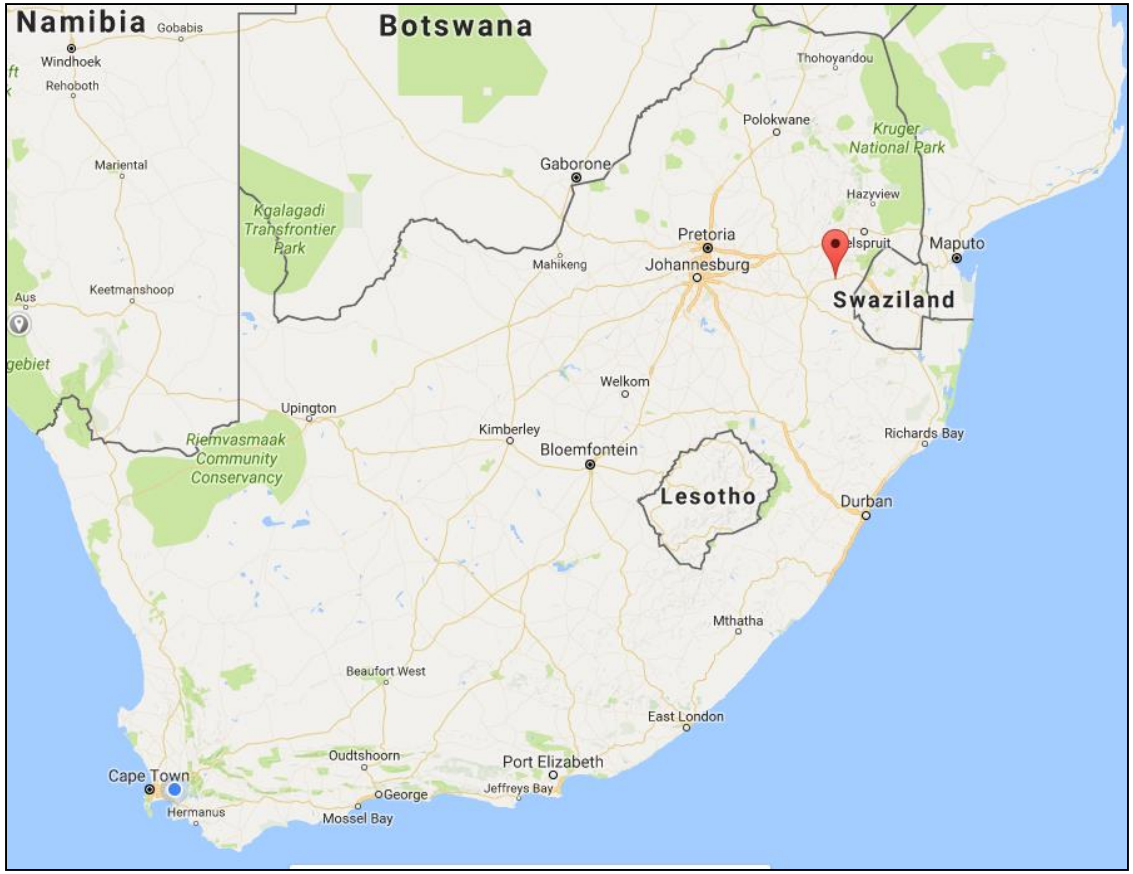
In field harvesting

- **Study Site:**



Methods

In field harvesting

- **Machine description:**

Ponsse Bear

Ponsse Beaver

Ponsse Buffalo

Ponsse Elephant King

Methods

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).

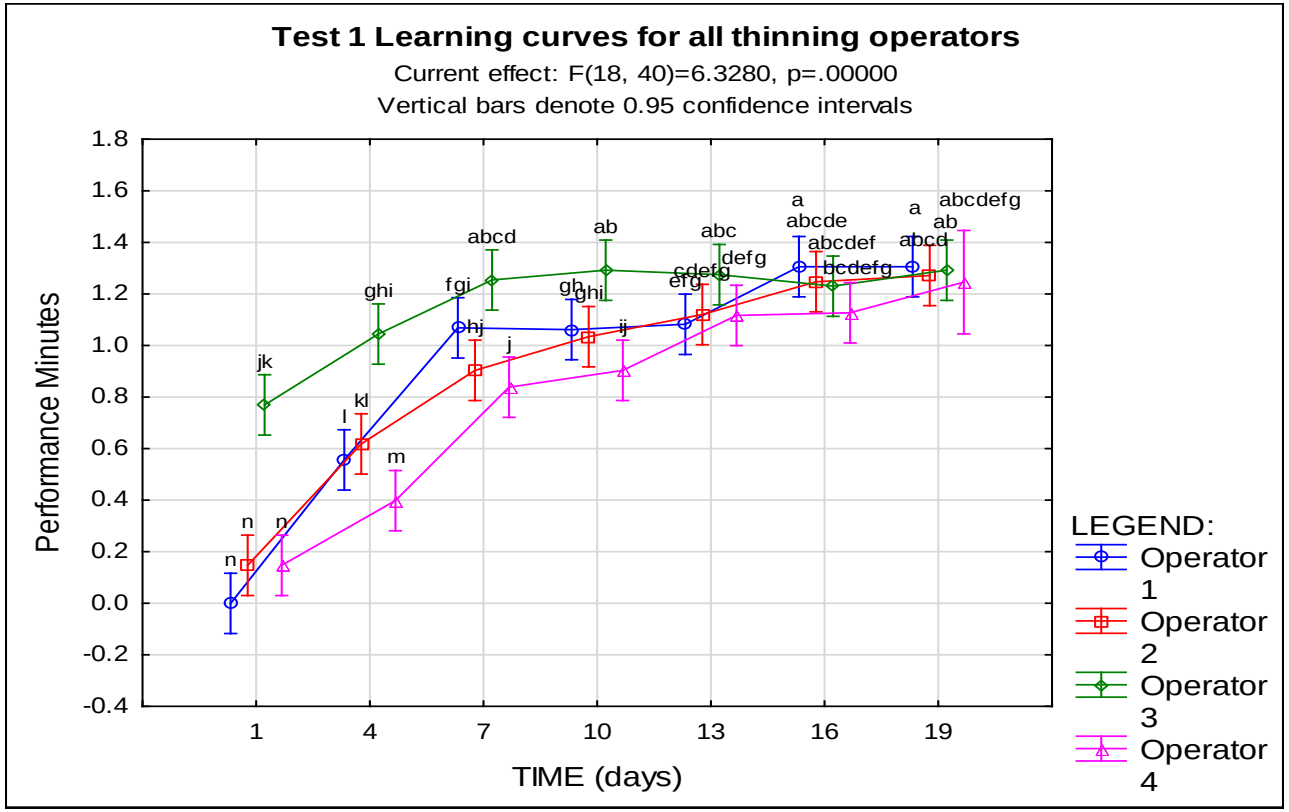
Results (Selection)

- 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

Operator number	Age	Eye-hand-foot coordination and auditory discrimination in:			Time Anticipation/ MDT	Direction Anticipation/MDD	Speed/ overall mean duration	Accuracy / overall % error duration	Cognitrone	Signal detection	Overall performance
		Normal situation. 1st interval	Crisis situation. 2nd interval	Recovery [from crisis]. 3rd interval.							
1	24	A	A	A	B	B	A	A	A	A	A
2	22	A	A	A	B	B	A	B	A	A	A
3	24	A	A	A	A	B	A	A	A	A	A
4	30	A	A	A	B	B	A	B	B	B	B
5	28	B	A	A	B	B	A	A	A	A	A
6	19	A	A	A	B	C	B	B	B	A	B
7	21	A	A	A	A	C	A	A	A	A	A
8	26	A	A	A	A	B	A	A	A	A	A

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.



Results

- Simulator training Test 1 (Thinning trainees):

Test 1: Test Time							
Trainee	PL start	Days to reach PL = 1	PL end and days to reach the end		Increase PL		PL max
					Overall	Per day	
			PL End	Days	%	%	
1	0	6	1.3	16	130	8.12	1.30
2	0.19	9	1.25	16	557.89	34.86	1.30
3	0.79	4	1.3	7	64.56	9.22	1.30
4	0.19	12	1.1	16	478.95	29.93	1.25
Mean	0.29	7.75	1.24	13.75	307.85	20.54	1.29
Median	0.19	7.50	1.28	16.00	304.47	19.58	1.30
25% - quantile	0.05	4.50	1.14	9.25	80.92	8.40	1.26
75% - quantile	0.64	11.25	1.30	16.00	538.16	33.63	1.30

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:

	Thinning			Clear-felling		
	DBH (cm)	Height (m)	Tree volume (m^3)	DBH (cm)	Height (m)	Tree volume (m^3)
Mean	21.98	11.59	0.18	29.78	19.59	0.54
Median	20.7	11.63	0.14	29.8	19.68	0.51
Range (min–max)	11–49.8	7.2–24.8	0.02–1.69	14–48.4	10.1–30.0	0.05–1.99

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.

Work month: 1	Y = 29.0459+26.2893*log10(x)
Work month: 2	Y = 28.7097+19.053*log10(x)
Work month: 3	Y = 31.9778+17.5296*log10(x)
Work month: 4	Y = 43.6702+25.0394*log10(x)
Work month: 5	Y = 43.6615+25.5174*log10(x)
Work month: 6	Y = 60.463+37.5663*log10(x)
Work month: 7	Y = 52.7036+32.328*log10(x)
Work month: 8	Y = 47.6553+28.2842*log10(x)
Work month: 9	Y = 50.2486+29.731*log10(x)
Work month: 10	Y = 45.1178+25.124*log10(x)
Work month: 11	Y = 59.0114+38.6558*log10(x
Work month: 12	Y = 60.87+40.4789*log10(x)

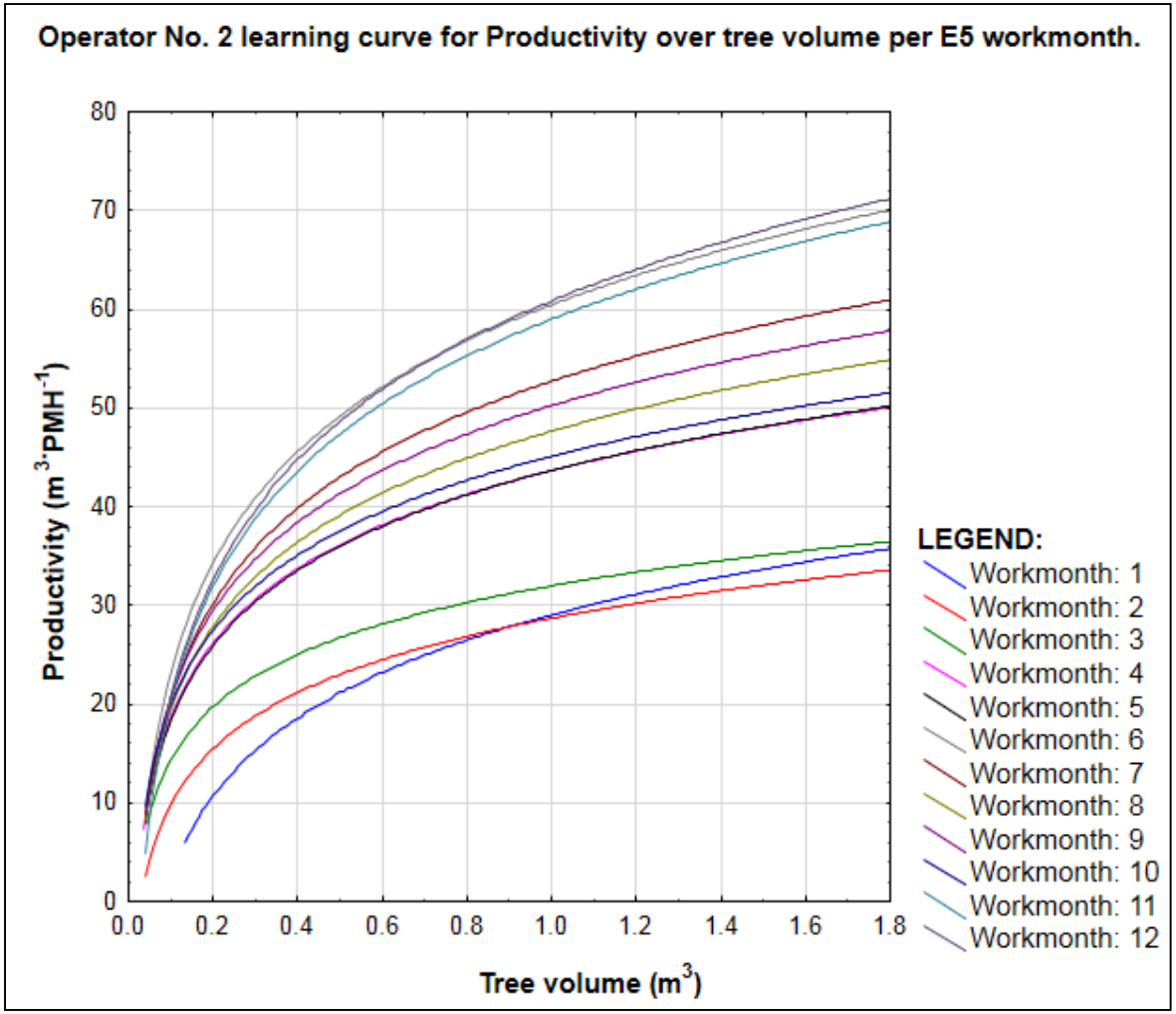
Where:

Y= Productivity ($m^3 \cdot PMH^{-1}$); and

X= Tree Volume (m^3)

Results

Thinning Operator No 2 productivity learning curve (I)



Results

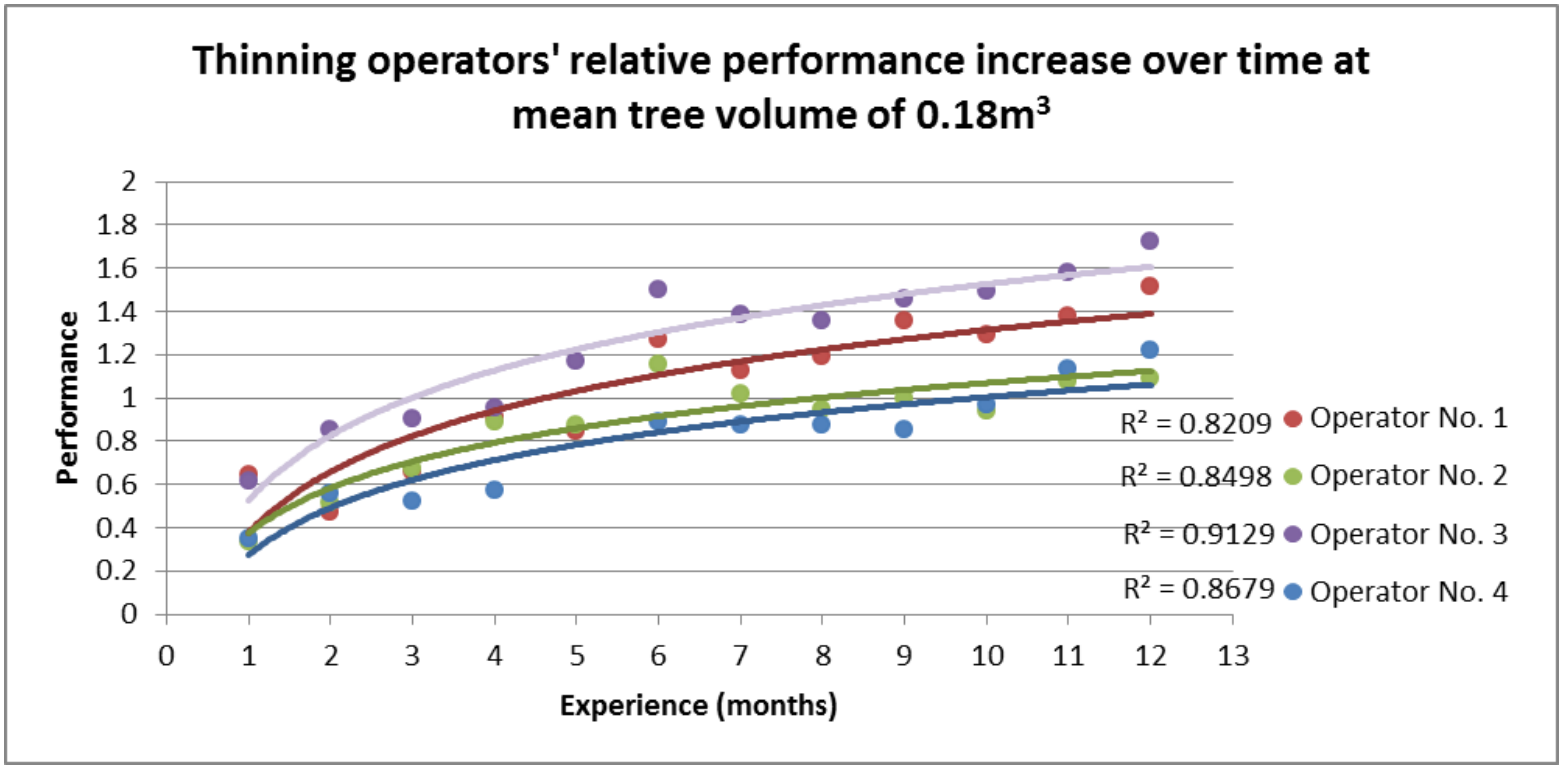
- Thinning Operator No. 2 productivity leaning curve (I) summary

Tree Volume (m^3) class measured at	Start Productivity ($m^3 \cdot PMH^{-1}$) (month 1)	End productivity ($m^3 \cdot PMH^{-1}$) (month 12)	Increase in productivity (%)
0.2	10	35	250
0.6	25	50	100
1	28	60	114
1.4	30	68	127
1.8	36	70	94
Overall	25.8	56.6	119

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

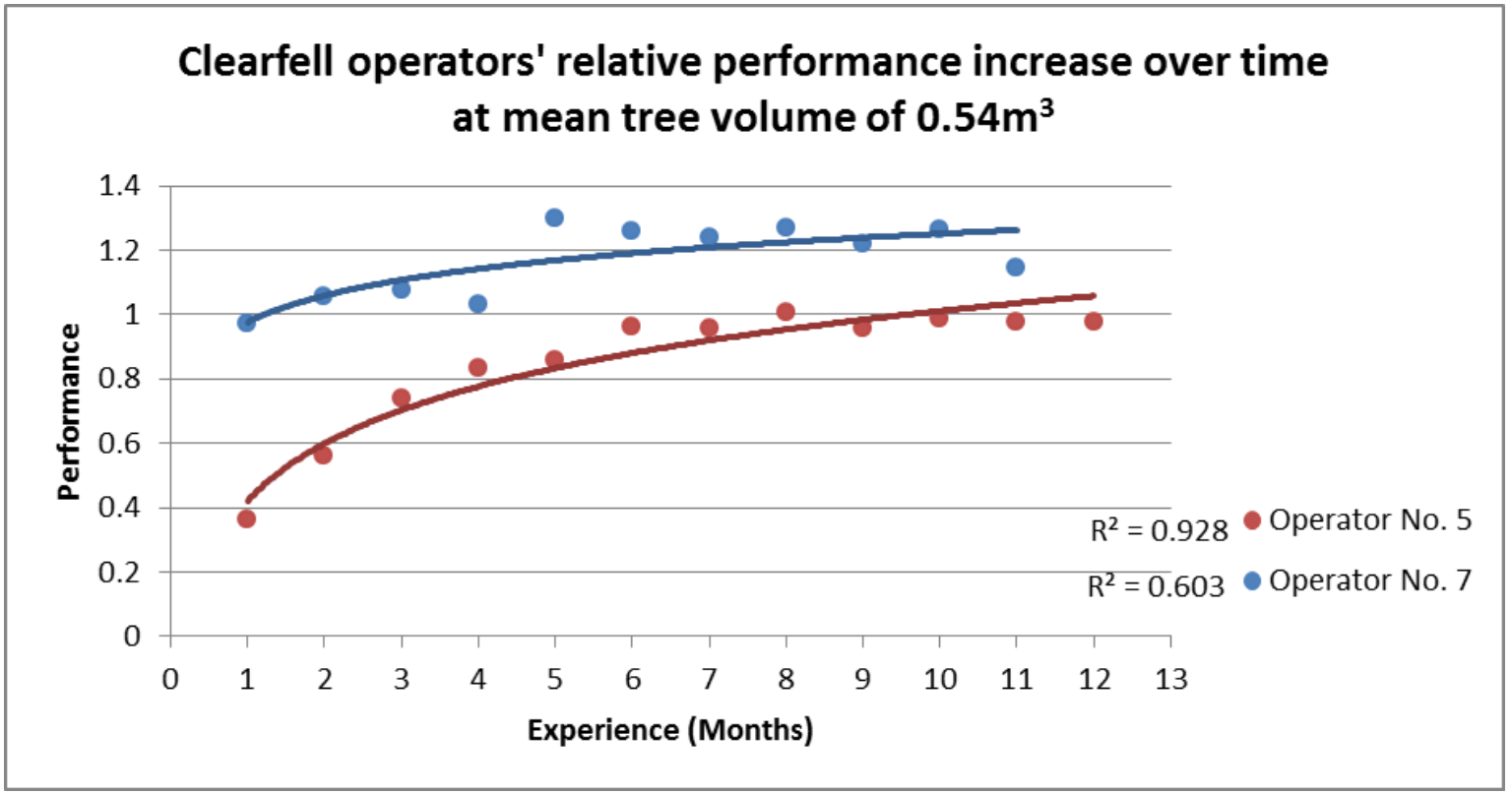
Results

- **Thinning operators performance learning curve (II)**



Results

- **Clear-fell operators performance learning curve (II)**



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

Discussion (Simulator training)

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 for 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 test)
  - 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 = 0.18m^3
  - Month 1 productivity = 13.71 $m^3 \cdot PMH^{-1}$
  - Month 12 productivity = 38.96 $m^3 \cdot PMH^{-1}$
  - Mean productivity = of 28.8 $m^3 \cdot PMH^{-1}$

- Clear-fell operators
  - Mean tree volume = 0.54 m^3
  - Month 1 productivity = 27.5 $m^3 \cdot PMH^{-1}$
  - Month 12 productivity = 43.75 $m^3 \cdot PMH^{-1}$
  - Mean productivity = of 41.9 $m^3 \cdot PMH^{-1}$

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

Tree volume	0,2	0,2	1,4	1,4
Productivity range	Start Productivity ($m^3 \cdot PMH^{-1}$) (month 1)	End productivity ($m^3 \cdot PMH^{-1}$) (month 12)	Start Productivity ($m^3 \cdot PMH^{-1}$) (month 1)	End productivity ($m^3 \cdot PMH^{-1}$) (month 12)
Operator No 1	16	40	25	84
Operator No 2	10	35	30	68
Operator No 3	20	50	50	96
Operator No 4	10	32	34	72

  - Clear-fell operators

Tree volume	0,2	0,2	1,4	1,4
Productivity range	Start Productivity ($m^3 \cdot PMH^{-1}$) (month 1)	End productivity ($m^3 \cdot PMH^{-1}$) (month 12)	Start Productivity ($m^3 \cdot PMH^{-1}$) (month 1)	End productivity ($m^3 \cdot PMH^{-1}$) (month 12)
Operator No 5	8	20	24	76
Operator No 7	15	24	64	85

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

Trainee	Overall Psychometric result	Simulator test results					
		Test1			Test2		
		Start PL	End PL	Days to end PL	Start PL	End PL	Days to end PL
1	A	0	1.3	16	0.55	1.4	6
2	A	0.19	1.25	16	0.3	1.1	6
3	A	0.79	1.3	7	0.25	1.4	7
4	B	0.19	1.1	16	0.35	1.2	6
5	A	0.5	1.35	7	0.2	1.15	4
6	B	0.65	1.2	10	0.55	1.2	4
7	A	0.4	1.2	10	0.7	1.2	3
8	A	0.6	1.35	10	0.15	1.2	6