Original scientific paper

Productivity of Cut-to-Length Harvesting by Operators' Age and Experience

Jukka Malinen, Janne Taskinen, Timo Tolppa

Abstract

In the study, the relationship between operators' age, experience and mechanized cut-to-length (CTL) harvesting productivity was examined. The data were five-year follow-up data from 28 operators and 38 CTL harvesters collected from southern Finland. Productivities were converted to relative productivities and average productivity models were created. Case specific productivities were compared to modelled values, and productivity ratio models including separate lower and upper quartile models were produced.

The relative productivity of operators at the age of 45 years in clear cuttings was 17.8% higher and in thinnings 14.9% higher than that of operators at the age of 25 years. The relative lower quartile productivity increased from operators aged 25 to operators aged 45 years by 38.6% in clear cuttings and 29.4% in thinnings. The relative productivity of operators having experience of 20 years was 23.6% higher in clear cuttings and 16.2% higher in thinnings than that of operators having experience of 3 years. Operators' experience of 20 years produced 43.1% better lower quartile relative productivity in clear cuttings and 29.1% in thinnings compared to 3 years' experience. The relative upper quartile productivity was 5.7% higher in clear cuttings for operators aged 45 years than for operators aged 25 years, but otherwise, there was no statistical correlation between upper quartile productivity and age or experience.

As a conclusion, CTL harvester operators' average productivity increases slowly after the initial learning phase up to 15 years of experience. The peak productivity was uncorrelated to age or experience, but the experience raised the bottom productivity values.

Keywords: human influence, harvester operator, learning, ageing, experience

1. Introduction

Cut-to-length (CTL) harvesters are expensive forest machines, and high investment demands high productivity in order to guarantee investment profitability. Productivity of a CTL harvester depends on numerous variables, stem size being the most recognised (e.g. Jiroušek et al. 2007, Erikson and Lindroos 2014). In addition to stem size, operator effect can be noteworthy (e.g. Kärhä et al. 2004, Purfürst 2010), although other stand properties affect productivity as well (Erikson and Lindroos 2014).

Productivity of forest machines has traditionally been measured by manually collected work studies. However, during the last decade, automatic collection of productivity data has become possible (Nuutinen 2013, Erikson and Lindroos 2014, Manner 2015). This kind of data collection enables long term follow up studies, which offers the option to analyse development of productivity at the level of a single machine or operator.

As the harvesting operational environment is difficult to change, used machinery and the operator's capabilities are under scrutiny when aiming to enhance productivity. The operator's productivity can be improved through education and gained experience (Ovaskainen 2004). In some countries, for example Finland, forest machine operators are systematically trained through vocational education, where students train on basic operations through simulator training and supervised learning at work (Certificate supplement 2015). This education, however, does not guarantee professional level productivity from an operator, merely a basis for a lifetime of learning through experience.

The learning process of an inexperienced harvester operator is called a learning curve (Purfürst 2010). It describes the level of performance and productivity, which evolves through learning time. Typically, the learning curve of a forest machine operator is described as having the shape of a sigmoidal model (Purfürst 2010). At first, an operator faces the phase of a »slow beginning«, where learning of the basics is occurring. In the second phase, »steep progress«, there is a steep rise which indicates that the rate of improvement is substantial and moves become »automatic«. In the third phase, »plateau«, the learning process becomes slower and the operator has reached the professional level. This, however, does not have to be the maximum level of performance. As the operator gains experience, the collection of available »proven solutions« accumulates and the work becomes easier and more automated.

According to Purfürst (2010), most operators begin their career between 50% and 60% of the mean performance and double their performance by the end of learning phase, which lasts on average 8 months. Gellerstedt (2002) noted that, according to machine instructors and trade union representatives, operators' learning time to get full efficiency takes about five years. In general, job experience improves productivity in several years, but there does come a point where experience does not increase productivity (Skirbekk 2003). Ericsson and Lehman (1996) state that it takes about 10 years to achieve expert competence in tasks where strategic and analytic competence is important.

Ageing of operators also has an effect on productivity and work quality. According to Skirbekk's literature survey (2003), cognitive abilities, reasoning, speed and episodic memory decline significantly before 50 years of age, and continue declining more thereafter. This leads to lower productivity, unless longer experience and higher levels of job knowledge compensates for the declines in mental abilities. However, there are indications that exercising or using speed, reasoning and memory abilities enhance the functional level and soften or halt age-related decline (Skirbekk 2003).

An operator's cognitive performance may vary due to life conditions, shift arrangements and environmental stimuli. For example, lack of quantity and quality of sleep, available light, air quality and cabin conditions, such as vibration and noise, are stress producers that make cognitive tasks more difficult. This, however, does not necessarily have to affect actual performance (Ljungberg and Neely 2007). In the study by Nicholls et al. (2004), a 2-shift regime was compared to a 1-shift regime, and over a 24-hour period, the 2-shift regime produced only 22% more wood than the 1-shift regime, although it took 62% more time. In a 2-shift operation, both day shift and afternoon shift operators were slow to reach optimum productivity from the start of the shift.

The aim of the study was to examine the relationship between operators' age, experience and mechanized harvesting productivity in clear cutting and thinning. The used data were long-term data collected from southern Finland by one Finnish forest machine company. The data included 28 operators and 38 different CTL harvesters. Recorded productivities were transformed to relative productivities and average productivity models were created. Case specific productivities were compared to modelled values, and productivity ratio models by age and experience were created.

2. Material and methods

2.1 Harvester data

The study data were collected by one Finnish forest machine company. The data included 38 different CTL harvesters (Table 1), from which the production files (prd-files) and time files (dfr-files) were recorded (Skogforsk 2007). The harvesting took place between October 2010 and November 2015, and the data included 802 thinning stands and 582 clear-cutting stands located in southern Finland, in the regions of Pirkanmaa and Kanta-Häme. The total harvested volume was 462,320 m^3, of which 181,113 m^3 was harvested from thinnings and 281,207 m^3 from clear-cuttings.

The study data included 28 operators, who were mostly quite experienced in their work. Operators were operating for the same forest machine company and they did not have fixed harvesters, although the

Table 1 Harvesters used in the study data collection

Manufacturer	Model	Number of machines
John Deere	1070D	10
John Deere	1170E	8
John Deere	1270D/E	13
Komatsu	901TX	3
Komatsu	911.5	1
Komatsu	931.1	3

Table 2 Harvester operators in the study data

	Age class						
	20–24	25–29	30–34	35–39	40–44	45–50	50–54
Number of operators	2	4	5	11	2	3	1
Average experience, years	3	6	11	14	19	25	28
Minimum experience, years	3	5	4	10	16	25	28
Maximum experience, years	4	7	13	18	21	26	28

make and type of the machine remained usually the same. Moreover, the forest machine company uses relatively young harvester fleet, and therefore the machinery was mainly renewed at the end of the study. Some of the operators started their employment during the study period and therefore their recorded study span was under five years. The average age of the operators at the end of the recording period was 35 years and the average experience in operating a CTL harvester 14 years (Table 2). Previous experience was collected through operator interviews and the age and experience, accumulated since the beginning of the study, was added to each recorded observation.

The collected data files were combined using John Deere Forestry's TimberOffice 5 software, and further processed in Excel-spreadsheets. Productivities were calculated as gross effective time productivity (E_{15}), which includes delays shorter than 15 minutes. Each productivity recording had to be solely allocated to one harvester operator. If a stand had two operators working in two shifts, the stand included two productivity values. If one stand had more than two operators, the stand was left out from the study.

2.2 Productivity model

The study data were divided into two segments, thinning stands and clear-cutting stands. For both segments, a productivity model by average stem size was modelled. The level of productivities in the data were considered confidential, and the data is presented as relative volumes compared to an arbitrarily selected volume, which was given a value of 100. The arbitrarily selected volume for the thinning data was 0.144 m^3 and for the clear-cutting data 0.501 m^3. The use of scaled values does not affect the results of the study since the aim of the study was to investigate relative productivity of the operators, not the actual level of productivity. For the comparisons of operator's productivity against modelled average productivity, the operator's relative productivity (P_r) was calculated by dividing the stand and operator specific actual productivity ratio (P_0) by modelled productivity ratio (P_m). Relative productivities for thinnings and clearcuttings, respectively, were

$$P_{rt} = \frac{P_{0t}}{P_{mt}} = \frac{P_{0t}}{-915.68 \times T_{volt}{}^2 + 644.96 \times T_{volt}} \quad (1)$$

and

$$P_{rcc} = \frac{P_{0cc}}{P_{mcc}} = \frac{P_{0cc}}{-175.64 \times T_{volcc}{}^2 + 332.54 \times T_{volcc}} \quad (2)$$

Where:

- P_r relative productivity
- P_0 operators actual productivity ratio, m$^3_{\%}$/E_{15}
- P_m modelled productivity ratio, m$^3_{\%}$/E_{15}
- T_{vol} Relative average volume in the stand, m^3
- t thinning
- cc clear-cutting.

Both productivity ratio models (P_{mt} and P_{mcc}) were forced to go through origin, and the coefficient of determination for the thinning model was 0.589, and 0.436 for the clear-cutting model. Productivity ratios were used in modelling relative productivity by age and by experience. In order to discover the development of operators' peak performance and also lowermost performance, upper and lower quartiles were calculated by dividing the data into 5 year categories. Age categories started from 20 years and experience categories from 0 years. Within each category, 25% of the best productivities were the upper quartile relative productivities and, respectively, 25% of the lowest productivities were the lower quartile relative productivities. These upper and lower quartile relative productivities were used to model upper and lower quartile relative productivity models. All relative productivity ratio models were second degree polynomial models where the age or the experience of the operator was used as a predictor variable.

Table 3 Model parameters for relative productivity models

Model	Parameter-estimates							
	n	Constant	*x*	x^2	R^2	SE	*F-value*	*p*
Age in clear cuttings								
q_{25}	147	–0.28965	0.04902	–0.00053	0.374	0.108	43.029	<0.001
All	582	–0.04857	0.05464	–0.00067	0.070	0.226	21.750	<0.001
q_{75}	147	0.35495	0.05251	–0.00070	0.093	0.135	7.419	<0.001
Experience in clear cuttings								
q_{25}	146	0.48391	0.03601	–0.00092	0.360	0.119	40.214	<0.001
All	582	0.77335	0.03437	–0.00097	0.084	0.224	26.616	<0.001
q_{75}	146	1.24272	0.00864	–0.00027	0.010	0.139	0.731	0.482
Age in thinnings								
q_{25}	202	0.01938	0.03385	–0.00035	0.204	0.139	25.481	<0.001
All	802	0.50526	0.02417	–0.00024	0.037	0.246	15.406	<0.001
q_{75}	202	1.33130	–0.00051	0.00002	0.003	0.152	0.264	0.768
Experience in thinnings								
q_{25}	200	0.57411	0.02346	–0.00054	0.195	0.142	23.902	<0.001
All	802	0.88571	0.01905	–0.00044	0.040	0.246	16.723	<0.001
q_{75}	200	1.32584	–0.00068	0.00008	0.006	0.156	0.595	0.553

* *n* – number of observations; *x* – predictor variable, R^2 – coefficient of determination; *SE* – standard error; q_{25} – lower quartile; q_{75} – upper quartile

3. Results

The age and experience of harvester operators were highly correlated (0.947). The youngest age to start operating a CTL harvester was 17 years, the oldest age was 28 years and the average age was 22 years. The experience of operators aged between 30 and 40 years varied between 3 and 18 years. The model parameters for the relative productivities by the harvesting type, and age and experience are presented in Table 3.

3.1 The effect of age and experience on productivity in clear cuttings

According to the model, the peak of productivity was in the age range of 40 to 45, after which there was a slight decrease in the productivity (Fig. 1). All operators over 40 were highly experienced with at least 16 years of experience. The relative productivity according to the model at the age of 25 was 0.90, whereas at the age of 45 it was 1.06, 17.8% higher than at the age of 25. The increase is explained by the lack of low

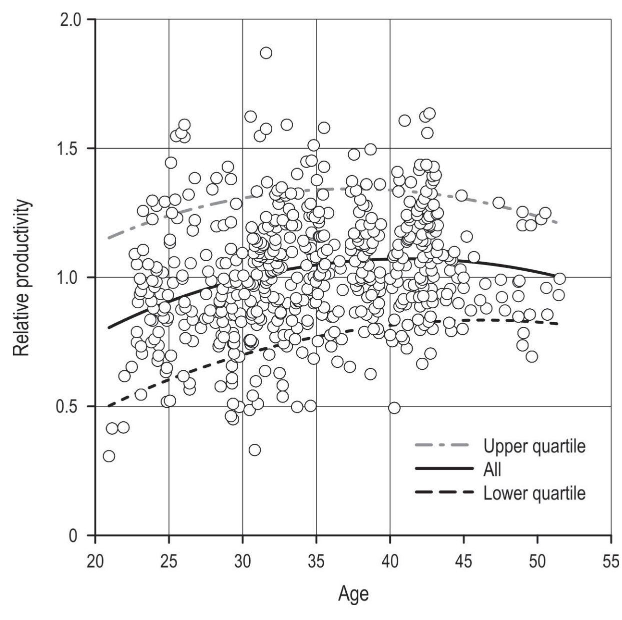

Fig. 1 Relative productivity of CTL harvester operator in clear cuttings by operators' age

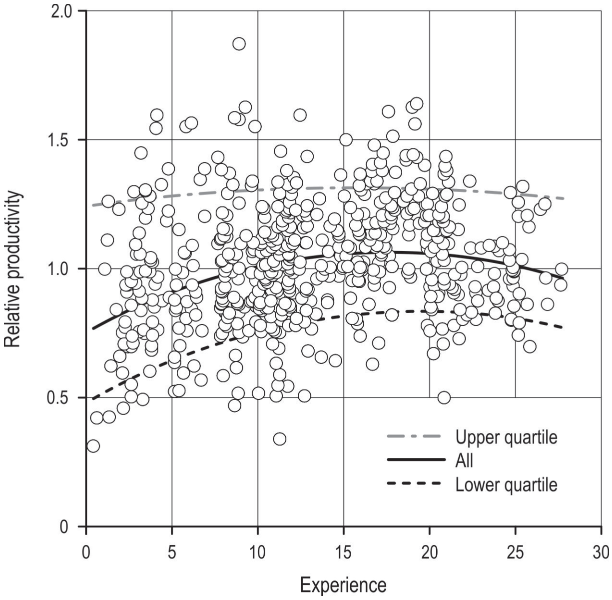

Fig. 2 Relative productivity of CTL harvester operator in clear cuttings by operators' experience (years)

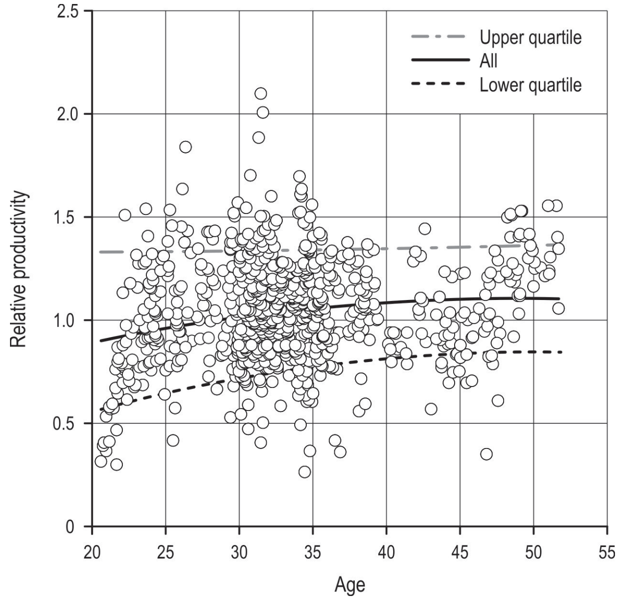

Fig. 3 Relative productivity of CTL harvester operator in thinnings by operators' age

productivity stands, the modelled relative lower quartile productivity increased from the age of 25 to 45 by 38.6%, while the modelled relative upper quartile productivity increased only by 5.7%.

The modelled relationship between experience and relative productivity was similar, as expected by the high correlation between age and experience (Fig. 2). Experience of 3 years produced relative productivity of 0.87, and 20 years of experience produced relative productivity of 1.07, 23.6% higher. However, the coefficient of determination and *p*-value for upper quartile model indicates (Table 3) that there is no statistical correlation between high level productivity and experience among studied trained CTL harvester operators. Conversely, according to the lower quartile model, increased experience improved lower quartile relative productivity by 43.1% from 3 years of experience to 20 years of experience.

3.2 The effect of age and experience on productivity in thinnings

The variation in relative productivity was higher in thinnings than in clear cuttings (Table 3). The modelled relative productivity increased quite constantly as the age of operator was higher, although the effect of age was smaller than in clear cuttings (Fig. 3). According to the model, the relative productivity increased from 0.95 to 1.09 (14.9%) between the operator's age of 25 and 45. According to the coefficient of determination and the *p*-value for the upper quartile model, age had no correlation with relative productivity. However, the productivity in the lower quartile model increased by 29.4% from the operator's age of 25 to operator's age of 45, explaining the total increase of productivity by age.

The experience of a CTL harvester operator had a similar relationship as age to productivity (Fig. 4). The

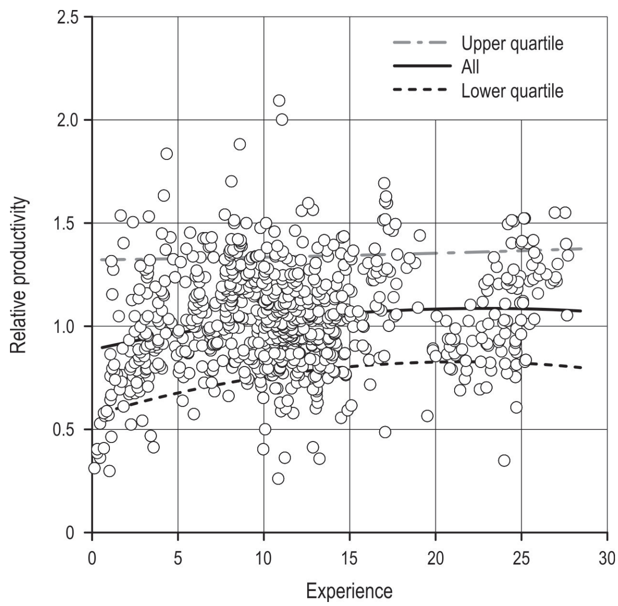

Fig. 4 Relative productivity of CTL harvester operator in thinnings by operators' experience (years)

operators experience level of 3 years produced relative productivity of 0.93, and 20 years of experience produced relative productivity of 1.09, 16.2% higher. Again, the coefficient of determination and *p*-value for the upper quartile model indicates that there is no statistical correlation between high level productivity and experience among trained CTL harvester operators. Higher experience in the model improved lower quartile relative productivity by 29.1% from 3 years of experience to 20 years of experience.

4. Discussion

In the study, the relationship between operators' ageing, experience and mechanized harvesting productivity was studied by using five-year follow-up data. The advantage of follow-up studies is that operators are unaware of data collection compared to time studies, where motivation and alertness is usually much better. Kuitto et al. (1994) found that productivity of forest transportation in a time study was 22.4% higher than the respective productivity in a follow up study.

The highest average relative productivity of individual operator was over 100% better than the smallest average relative productivity. Both the highest and the lowest average relative productivity were accomplished by fairly inexperienced operators, both having less than five years' experience at the end of the study, highlighting high personal differences between operators. High variance has also been found by Purfürst and Erler (2011). In their study, the best operator worked at a performance level of 125% compared to the relative mean performance level, whereas the worst operator had a mean individual performance of 56%. Lower variances have been reported by Glade (1999): 20–50%, Kärhä et al. (2004): 40% and Väätäinen et al. (2005): 40%. However, in this study, as in the study of Purfüst and Erler (2011), the number of operators was higher than in the studies with lower variance, which could explain some of the difference.

According to the relative productivity models, it took 8.8 years' experience in clear cuttings and 7.2 years' experience in thinnings to achieve the average productivity level. The respective ages of operators were 31 years for clear cuttings and 29 years for thinnings. These are long periods of experience, but they can be explained by the data in which the majority of the operators were in the age range of 35–39 with an average experience length of 14 years, thus highly experienced but still relatively young for this kind of work requiring high professionalism. However, the shorter time to achieve the average productive level in thinning than in clear cutting was controversial, as it meant making the generalised assumption that thinning is more demanding work than clear cutting. The result of this study is supported by Häggström (2015), who found out through a visual tracking study that harvester operators looked at their monitor, canopy and falling trees less frequently during the first thinning than during the second thinning and final felling. Although tree selection and strip road planning demand expertise in first thinnings, observation of quality and bucking decisions become more demanding in later thinnings and clear cuttings.

The peak in relative productivity models was found at comparatively high experience levels, although previous studies in other occupancies indicate that the productivity-enhancing effect of experience reaches its maximum at ten years (Ericsson and Lehmann 1996). Visual interpretation of the data reveals that the peak values in productivity are achieved at the experience level of 10 years, and these levels decrease slowly as the experience and age increase. At the same time, bottom productivity values are also closing in on average productivity values, leading to the conclusion that there is no clear indication of a drop in productivity due to ageing, although values slowly decrease especially in clear cuttings. This is in line with the findings of Skirbekk (2008), productivity peaks in the age group of 35–44 if the occupancy demands a high level of experience. If the demand for experience falls, the productivity peak shifts toward younger ages.

Most typically, harvester operators' learning and experience studies have concentrated on the initial learning phase, that is, the phase when most of the productivity growth occurs, and lasts up to five years (Gellersted 2002, Purfürst 2010, Purfürst and Erler 2011). This study had only three operators whose experience during the study was under five years. However, the aim of the study was not to investigate the early years of learning, but the development of expertise among experts. Nevertheless, from the three operators, two operators had a learning phase under one year, whereas one operator was still developing after 2.5 years.

The information regarding forest machine operators' productivities and work quality is important for successful forest machine entrepreneurship. According to Purfürst (2010), a harvester operator in the learning phase may cost up to 45,000 Euros in the first eight months in productivity losses, and possibly increase wear and tear or repair costs. Feedback of the individual work performance and possible incentives could enhance motivation, quicken the learning process and improve stability in productivity.

5. Conclusion

According to study results, CTL harvester operators' productivity increases slowly, but steadily, after the initial learning phase up to 15 years of experience, indicating a high demand for experience in this field. High demand for experience keeps the productivity of ageing workers high, despite a possible reduction in cognitive abilities. The effect of ageing diminishes peak productivity, but at the same time the experience raised the bottom productivity values, leading to lower variation in the productivities. The demand for experience was higher in clear cuttings than in thinnings, which was a controversial finding to general estimations. The variability between observations and operators was high, emphasising personal differences affecting productivity between operators regardless of the age and experience.

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Authors' addresses:

Jukka Malinen, PhD. *
e-mail: jukka.malinen@uef.fi
University of Eastern Finland
School of Forest Sciences
Yliopistokatu 7
80101 Joensuu
FINLAND

Janne Taskinen
e-mail: janne.taskinen@mkpd.fi
Timo Tolppa
e-mail: timo.tolppa@mkpd.fi
Metsäkonepalvelu Oy
Konepajantie 12
13300 Hameenlinna
FINLAND

* Corresponding author

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