Productivity of Different Working Techniques in Thinning and Clear Cutting in a Harvester Simulator

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Abstract

The objective of this study was to compare the productivity of three working techniques in thinning and three working techniques in clear cutting using a single-grip harvester work. Typically, forest conditions are so heterogeneous that a reliable comparison between working techniques is not possible. For this reason, the experiments were performed using a harvester simulator environment, which enables very homogeneous experiment conditions for operators and therefore good comparability for the results: the same stand can be reloaded and cut with different working techniques using the same technical settings as many times as necessary. The studied working techniques in thinning were: right-angle piling, oblique piling and under the boom piling, and in clear cutting: one-sided piling, two-sided piling and forward felling. In thinning the difference in productivity of the least productive, right-angle piling, and the most productive, under the boom piling, was about 7%, which was mainly caused by the faster felling. In clear cutting, the productivity of forward felling and two-sided piling were similar (difference only about 1%). Their productivity was about 11% higher than one-sided piling. This difference was caused by faster (about 5 seconds) catching and felling. The results are useful from the perspective of the education and training of operator candidates.

Key words: cut-to-length, productivity, simulator, single-grip harvester, working technique

Introduction

Single-grip harvesters are widely used for felling, delimbing and crosscutting trees into logs at the stump (the cut-to-length method). In Finland and Sweden nearly 100% of the annual harvested timber is cut mechanically, mostly using single-grip harvesters (Metsätilastollinen vuosikirja 2009). Globally, during the last decade, mechanical tree harvesting and the cut-to-length- method (CTL) have increased at the expense of manual cutting and whole tree or tree length harvesting methods. It has been estimated that this trend will continue in the near future (Asikainen et al. 2009).

The productivity of single grip harvester work is based on three main factors: environment, harvester and operator. All of these are essential in determining productivity and are deeply interconnected. Tree size is the most determining variable of the environment: increasing tree size increases productivity, which has been proven in numerous studies around the world (Kellog and Bettinger 1994, Kuitto et al. 1994, McNeel and Rutherford 1994, Brunberg 1991, 1997, Landford and Stokes 1995, 1996, Lageson 1997, Eliasson 1998, Sirén 1998, Glöde 1999, Hånell et al. 2000, Ryynänen and Rönkkö 2001, Kärhä et al. 2004, Nurminen et al. 2006).

Harvesters are so effective that it only takes slightly more time to process a large tree compared to a small tree. This inevitably leads to an increase in productivity as stem size increases. In addition to tree size, the productivity of harvesters has been noticed to increase with increasing density of trees removed in clear cuttings (e.g. Kuitto et al. 1994, Brunberg 1997, Eliasson 1998, Sirén 1998), as well as in thinnings (Sirén 1998) and shelterwood cuttings (Hånell et al. 2000). Other factors that affect the productivity include the properties of the standing trees, terrain characteristics: slope (Stampfer and Steinmüller 2001), surface structure and bearing capacity (Ala-Ilomäki 2004). Weather conditions i.e. lightning, precipitation (water, snow) (Ala-Ilomäki 2006), temperature and snow depth may also influence cutting work.

Nowadays, harvesters of the same size have almost the same productivity in similar stands. The reasons for this are that harvesters are built up the same way and they use partially the same components. Therefore the machines are quite similar (Ovaskainen 2009). Nevertheless, a higher level of productivity is sought by the customers, as well as harvester manufacturers, in order to keep down the cutting costs. Increasing productivity through technical solutions is expected to be an expensive way of increasing the productivity and is expected to increase the cost of the machine and thereby the hourly costs. Hence, the reduction in the importance of the brand of the harvester places more significance on the skills of the harvester operators. Therefore, the focus has been directed on operator skills and, especially, on operator training, as the harvester operator significantly influences the productivity (Sirén 1998, Sirén andRanttu 2001, Kariniemi 2006). More than 40% differences in productivity have been observed between operators in similar cutting conditions (Ryynänen and Rönkkö 2001, Ovaskainen et al. 2004). Therefore, the operator and their technique of operating the harvester have considerable impact on the cutting results.

Depending on the study's focus harvester productivity can be studied on stand, working location or single tree level (Ranta 2003). Typically, the stand level has been used to present the working methods of the harvester (e.g. Suadicani 2004). On the working location level, the processing order, processing place or the number of removable trees in a certain working location has been studied (Wigren 1992, Nurmi 1994). On a single tree level the focus is on a single tree at a time: distance to the tree to be felled, felling direction and moving distance of the tree after felling are examples of measured variables (Ovaskainen et al. 2004). Previous studies have mainly focused on the stand level, while studies on the lower levels have been made mainly in the PC simulation environment on the basis of deterministic rules without situation-specific human influence as that the question is in a virtual harvester simulator (Eliasson 1999, Wang and LeDoux 2003, Wang et al. 2005).

Nowadays, virtual harvester simulators are mainly used in harvester training schools. However, simulators are also suitable for studying harvester work (Ovaskainen 2005), especially for testing various innovations (Ranta 2003, Löfgren 2009). In a virtual environment, studies are relatively inexpensive compared to studies in a real environment, because most of the stand measurements are obtained automatically from the simulator. In addition, varying terrain conditions can be standardized and simplified: the same stand can be cut in various ways and reloaded as many times as necessary, also allowing the elimination of factors that cause outliers. In the simulator environment, crane motion lines and operating speeds must be realistic and the same between operators, as well as modelling of the movement of the machine must be realistic.

The influence of the operator on the productivity can be divided into rating and working technique (Ovaskainen 2009). Rating is generally defined as "the assessment of the worker's rate of working relative to the observer's concept of the rate corresponding to standard pace" (Anon 1981). In harvester work, rating would mean perceivable speed that is visible in work functions and is highly dependent on the operator's cognitive abilities and sensomotoric skills in the present-day harvester work (Gellerstedt 2002, Ovaskainen 2009). In practice, it is the speed at which the work movements, such as driving and moving the harvester head, are made. On the other hand, working technique, according to one definition, is understood to be the visible and measurable movement of harvester and harvester head from one place to another (Ovaskainen 2009). Working technique always includes some amount of operator-specific features of the harvester work and also personal tacit knowledge to a certain degree. In addition, in different working techniques trees are moved different distances. By understanding the working technique as an examination of movement of the harvester head and machine, the harvester simulation environment provides reliable results, since the crane speeds are the same for all operators. However, different kinds of working techniques can be classified on the basis of their differences in work results (e.g. pile size, pile angle) and the method of using the harvester head. Typically working techniques differ in work elements regarding tree catching distances, felling directions, tree moving distances, processing locations in relation to the harvester and the angles of bunching of processed logs. Therefore, some working techniques diminish unnecessary work elements, and are therefore more productive. Harvester working techniques, especially thinning techniques, have not been studied as much as their importance necessitates, but some studies can be found (Wigren 1992, Nurmi 1994).

This study focuses on different working techniques, which are measurable and more practical to improve than operator's rating. By improving working technique or changing the technique, additional cubic meters can be achieved in cutting. Therefore, the hypothesis is that different felling direction and/or different moving direction of the cut trees will affect productivity of harvester thinning operation or final felling. As Nurmi (1994) suggest, forward felling was more productive than one sided-piling in clear cutting.

The objective of this study was to compare three working techniques in thinnings and three working techniques in clear cuttings and examine which work elements cause the differences.

Materials and methods

Operators and virtual environment

The work of five different operators was studied using a harvester simulator: operator 1-4 operated the simulator in thinnings and operator 1-3 and 5 operated in clear cuttings. Operators 1-3 had over five years experience of operating real harvesters in both thinnings and clearcuttings. Operator 5 was experienced only in clear cuttings and operator 4 only in thinnings. They both had about three years of experience. All the operators were able to operate fluently in the harvester simulator despite the minor differences to real harvesters. The operators were allowed to train on the harvester simulator as much as they felt necessary so they could operate on the same working speed in all the experiments. Some of the operators did not use all the techniques in their normal work so the learning and internalizing of a certain technique was controlled for each operator before the experiment. The boom speed was set to be the same for all the operators.

The harvester work was simulated by using a Timberjack harvester simulator, which is equipped with real harvester control levers, including a complete Timbermatic 3000 system (Figure 1). The virtual harvester was Timberjack 1270D with 746 harvester head mounted to 10 m long crane. The hardware elements such as operator chair, controls, and onboard computer are as in real machines, and the software is programmed accordingly. View from the cabin of the harvester is projected onto the wall in front of the operator and the view follows the direction of the boom.

Figure 1. Virtual forest harvester simulator

In the simulator, a generated stand consists of squares of 12.5 × 12.5 m. The stand generator creates five different kinds of squares and utilizes these randomly to fill the given stand area. In the squares trees are generated on the basis of tree height, species and density. The tree placements are random. The tree heights vary randomly between one metre below and above the selected height. Tree diameter at breast height, 1.3 m (DBH), is calculated on the basis of tree height.

The simulated harvesting studies were done in one simulated thinning stand dominated by Scots pine (*Pinus sylvestris*) and in one simulated clear cutting stand dominated by Norway spruce (*Picea abies* (L.) Karst.) (Table 1). In thinning, the share of tree species were pine 42.9%, spruce 28.6% and birch (B*etula pendula*) 28.6% while in clear cutting all the trees were spruces. Operators cut totally 727 trees in thinning and 619 trees in clear cutting, and the average amounts of extractions were 61.1 m^3/ha and 344.7 m^3/ha, respectively. The average volume of stem was the merchantable part of the stem: over bark minimum in diameter 6 cm for spruce and pine and 5 cm for birch.

Table 1. The characteristics of the harvested stands

Environment	Trees /ha	Average volume, m^3	Average height, m	Average diameter (DBH), cm
Thinning				
Before cutting	896	0.233	13.0	20.7
SD[a]			2.46	3.80
After cutting	576	0,255	13.6	21.8
SD[a]			2.27	3.52
Extraction	330	0,185	12.0	19.1
SD[a]			1.09	1.68
Thinning ratio[b]				0.88
Clear cutting	432	0.798	20.7	32.8
SD[a]			2.53	3.93

a SD = standard deviation
b Thinning ratio is average diameter (DBH) of extracted trees divided by average diameter of the residual trees (after treatment).

The simulated ground was flat and contained no terrain obstacles that could cause systematic time outliers to the data. The duration of one simulated harvesting plot was set to about 45 minutes. When the next plot for the next working technique was recorded the simulated stand was loaded again and the experiment began from the same starting point as the previous one. Each operator cut one experiment with each technique. The operators could choose the cutting order of the experiments because some of the techniques were more familiar.

In clear cutting the border of the stand to be followed with the harvester was marked and the operator could choose freely the trees to be removed and their order of removal. In the thinning, the place for the strip road to be created by the operator was marked with blue poles and the removable trees to be removed with red marks at breast height level in order to make operators fell the same trees in all experiments. In a real thinning, trees to be removed are typically not marked in Finland. However, the operator could choose the order of removal according to the working technique. The operators were instructed to process trees automatic. In other words, the operators did not change the suggested cutting points or feed the trees manually. Therefore, the processing was not influenced by the operator other than the time it takes to activate the saw in cross cutting.

Time study data

The harvester operators' work was measured using a time study method where the work was divided into five main work elements: moving, catching, felling, processing (including delimbing, crosscutting and placing of logs), and non-productive time.

• Moving began when the harvester wheels started to roll and ended when the wheels stopped rolling. Even though the machine can perform other work elements while rolling other work elements are only registered when the machine is not moving.

• Catching started after stop in moving or after processing (after the harvester head has been tilted to an upright position). Typically catching started with a boom swing toward a tree and ended when the felling began.

• Felling started when the felling saw started to cut and ended when the feeding rollers started to roll.

• Processing started when the feeding rolls started to roll. The processing ended when the operator tilted the harvester head to an upright position.

• Non-productive time included all the work time when any control button was pushed or lever steered in other words the machine was not steered. Clearing of non-commercial trees was included in this time.

Non-productive time was recorded but it was not further examined in the results because in this kind of experimental study design there were no such delays as in the real environment, such as the clearing of small size trees. All observations in the time study focused on one tree handling cycle at a time and the cycle time is a sum of the element times. The time study was recorded automatically by the simulator computer and the volumes of the cut stems were added to time units from saved stem files.

Studied working techniques

Three different kinds of working techniques were studied in thinning and three other working techniques in clear cutting (Figures 2 and 3). The techniques are chosen after methodical discussions with harvester operators and harvester school teachers. In thinning, the working technique 'right-angle piling' (1) means that the trees are felled mostly perpendicular to the strip road, the harvester head pulls the tree over the strip road and the trees are processed away from the strip road so that the piles are placed on both sides of the strip road at a 90 degree angle. In the working technique 'oblique piling' (2) means that the logs are piled obliquely to the strip roads. Felling direction is forward of the trees located on the strip road. Trees located near the strip road (3–6m) are felled forwards or towards the strip road at about 45 degree angle. Trees are typically dragged over the strip road before they are processed. The working technique 'under the boom piling' (3) means that the trees are mainly processed under the boom, the trees are fed towards the boom base. The felling direction of a tree is in the direction of where the boom points at the moment of felling. Trees on the strip road are felled forward along the strip road while near the strip road the trees are felled in the direction of the boom. This was also the case for the trees located far away from the strip road. In this technique trees are moved only a distance that fluent felling necessitates. The slash was not moved to the strip road which in many cases are wanted in order to increase bearing capacity and to protect the roots of the remaining trees.

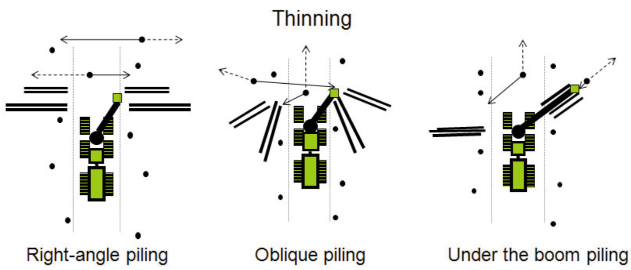

Figure 2. Studied working techniques in thinning. The dashed line arrows present felling direction and the solid line arrows moving direction of the tree

The three clear cutting working techniques included (1) one-sided piling, (2) two-sided piling and (3) forward felling. The 'one-sided piling' means that trees are processed only on one side of the harvester moving line. Trees are felled in front and obliquely front of the harvester from the opposite side of the processing side. Trees are felled at about a 90 degree angle to the harvester moving line when the pile will also be at a 90 degree angle in relation to harvester moving line. The working technique 'two-sided piling' means that the trees are felled in front and obliquely front of the harvester, moved and processed on both sides of the harvester moving line bringing the felled trees over the harvester moving line. In working technique 'forward felling' trees are felled along the strip road forwards, and the piles will be placed at the sides of the harvester almost along the harvester moving line. Trees are not moved over the harvester moving line. The size of the pile is typically increased by felling trees farther on by driving a little forward, reaching the tree and then backing, enabling the tree to be processed onto the existing piles. Otherwise the logging residues cover the tops of the logs. In the working techniques 'two-sided piling' and 'forward felling' the piles are organized so that the saw logs are located nearest the harvester and other assortments farther away from the harvester.

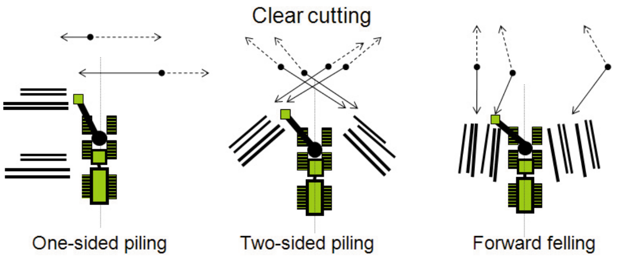

Figure 3. Studied working techniques in clear cutting. The dashed line arrows present felling direction and the solid line arrows moving direction of the tree

Statistical calculations

It is widely accepted that the operator influences the time consumption, with each operator having their own general working speed (rating). For this reason, the operators were tested individually assuming, on the basis of similarity in the study setting, that only the working technique influences the work element times of different techniques. To describe the differences between the working techniques, arithmetic averages were calculated for operators for moving, catching and felling times for each technique (see tables 2-6). Time consumption for processing was calculated with a linear model, which was formed by fitting a model to the operator's own data. In addition, work element time averages including observations (overall data) from all the operators for each working technique were calculated.

The focus on statistical testing was to determine if the work elements times of an operator in different techniques differ in general and which working techniques differ pairwise. In the data some of the variables were not distributed normally in the test of Kolmogorov-Smirnov normality test and some of the variances were not equal in the Levene's test so, for these reasons, the statistical testing were made with non-parametric tests. In non-parametric testing Kruskal-Wallis (K-W) assessed the statistical similarity of the working technique work element times and Mann-Whitney (M-W) was used in pairwise comparisons of working techniques work element times. The statistical significance level (p-value) was set to 5%. Effective productivities (E_0, excluding delays) between the techniques were compared with K-W test.

Results

Effective time

In thinning, the effective times of work cycles between working techniques did not differ statistically (K-W, p = 0.195) in the overall data (Table 2). In pairwise comparison, the techniques did not differ statistically from each other and the average times between working techniques were very similar. Only operator 4 had a difference in right-angle and under the boom piling techniques.

In clear cutting, the effective times of the work cycles differed statistically (K-W, p < 0.000) in the overall data. In pairwise comparison, one-sided piling differed from two-sided piling and forward felling. However, two-sided piling and forward felling did not differ statistically. The effective time in the work cycle was clearly the highest in one-sided piling.

Thinning

In thinning, overall moving time averages did not differ statistically significantly (K-W; p = 0.774) (Ta-

Table 2. Average times for effective work cycle times for each working technique for each operator in thinning and clear cutting environments. K-W – test indicates if the working techniques differ statistically significantly and M-W –test indicates the differing technique pairs

	Thinning					Clear cutting				
Technique/ Operator	Right-angle	Oblique	Under	K-W	M-W	One-sided	Two-sided	Forward	K-W	M-W
Op 1	40.3	38.8	41.2	0.406	-	57.4	51.6	53.6	0.002*	On-T; On-F
Op 2	43.8	41.6	44.3	0.412	-	56.5	49.5	52.9	0.001*	On-T; On-F
Op 3	41.1	38.2	38.0	0.816	-	63.0	47.8	52.8	0.000*	On-T; On-F
Op 4	40.2	38.4	34.5	0.075	R-U					
Op 5						54.8	53.4	49.6	0.145	-
Average	41.4	39.3	39.5	0.195	-	57.9	50.6	52.2	0.000*	On-T; On-F
SD	1.7	1.6	4.2			3.6	2.4	1.8		

* p-value less than 0.05

ble 3). Operator 3 had statistically significant difference in right-angle and under the boom piling techniques in pairwise comparison.

Table 3. Average times for work elements for each working technique for each operator in thinning environment. K-W -test denotes if the working techniques differ statistically significantly and M-W -test indicates the differing technique pairs

Thinning										
	Moving, s					Catching, s				
Technique/ Operator	Right-angle	Oblique	Under	K-W	M-W	Right-angle	Oblique	Under	K-W	M-W
Op 1	3.5	3.8	3.9	0.710	-	12.4	10.9	15.5	0.002*	**R-O; O-U**
Op 2	5.6	5.4	6.6	0.401	-	15.5	12.5	16.8	0.000*	**R-O; O-U**
Op 3	5.6	5.3	4.1	0.080	**R-U**	16.1	13.3	14.3	0.308	-
Op 4	3.6	4.1	3.3	0.521	-	16.9	15.9	15.1	0.697	-
Average	4.6	4.7	4.5	0.774	-	15.2	13.1	15.4	0.000*	**R-O; O-U**
SD	1.2	0.8	1.5			2.0	2.1	1.0		

	Felling, s					Processing, s				
Technique/ Operator	Right-angle	Oblique	Under	K-W	M-W	Right-angle	Oblique	Under	K-W	M-W
Op 1	11.5	11.0	8.7	0.000*	**R-U; O-U**	12.9	13.1	13.1	0.914	-
Op 2	7.3	8.2	6.9	0.085	**O-U**	15.4	15.5	14.0	0.624	-
Op 3	7.2	8.0	7.0	0.311	-	12.	11.8	12.6	0.207	-
Op 4	7.2	6.1	5.4	0.000*	**R-U; O-U**	12.5	12.3	10.7	0.003*	**R-U; O-U**
Average	8.3	8.3	7.0	0.000*	**R-U; O-U**	13.3	13.2	12.6	0.395	-
SD	2.1	2.0	1.3			1.5	1.6	1.4		

* p-value less than 0.05

The catching times differed statistically significantly between the working techniques in the overall data (K-W, p < 0.000). In pairwise comparisons, right-angle piling and oblique piling, and oblique piling and under the boom piling differed statistically. The same techniques differed in the data for operators 1 and 2. Catching time was the smallest in oblique piling for all the operators.

The felling times differed also statistically significantly between the working techniques (K-W, p < 0.000). In pairwise comparisons, right-angle piling and under the boom piling differed statistically significantly, as also was the case for oblique piling and under the boom piling in the overall data. However, right-angle piling and oblique piling did not differ statistically. Felling time was the lowest in under the boom piling technique for all the operators: on average, over a second faster than for the other techniques.

The processing times between working techniques did not differ statistically (K-W, p = 0.395) in the overall data. In pairwise comparisons of operators, all the techniques seemed to consume the same amount of time under statistical examination except for operator 4 whose under the boom piling technique seemed to consume less time than the other techniques. The work technique specific average times were very similar, only the under the boom piling was a little faster.

Clear cutting

In clear cutting, the moving times did not differ from each other statistically for the overall data (K-W, p = 0.089), but in pair wise comparison one-sided piling and forward felling differed statistically (M-W, p = 0.043), while the other pairwise comparisons were not statistically significant (Table 4). In forward felling, the moving time was generally the largest, but for some reason operator 5 was much faster than the other operators.

The catching times differed statistically from each other (K-W, p < 0.000) in the overall data. In the pairwise comparisons, one sided piling differed from forward felling and almost of the two sided piling. All the operators had the highest time consumption for catching in one sided piling.

In addition, the felling times differed statistically (K-W, p = 0.001). In pairwise comparisons, one-sided piling differed statistically from forward felling and almost for two-sided piling. However, two-sided piling and forward felling had a slight statistical difference. In one sided piling, the felling time was the highest for all the operators.

The processing times differed statistically (K-W, p < 0.000) in the overall data. In pairwise comparisons one-sided piling differed from two-sided piling and forward felling. On the other hand, two-sided piling and forward felling did not differ statistically. In one-sided piling the processing time was the highest.

Table 4. Average times for work elements for each working technique for each operator in clear cutting environment. K-W – test denotes if the working techniques differ statistically significantly and M-W -test indicates the differing technique pairs

Clear cutting										
	Moving, s					Catching, s				
Technique/ Operator	One-sided	Two-sided	Forward	K-W	M-W	One-sided	Two-sided	Forward	K-W	M-W
Op 1	5.3	4.7	6.5	0.337	-	14.7	13.7	12.0	0.019*	On-F
Op 2	4.9	6.5	7.8	0.017*	On-F	15.9	12.4	12.7	0.001*	On-T; On-F
Op 3	5.7	5.2	7.0	0.329	-	18.6	11.0	14.0	0.000*	On-T; On-F; T-F
Op 5	4.3	5.9	3.9	0.034*	On-T; T-F	13.5	11.7	13.1	0.104	-
Average	5.1	5.6	6.3	0.089	On-F	15.7	12.5	12.4	0.000*	On-F
SD	0.6	0.8	1.7			2.2	1.2	0.8		
	Felling, s					Processing, s				
Technique/ Operator	One-sided	Two-sided	Forward	K-W	M-W	One-sided	Two-sided	Forward	K-W	M-W
Op 1	12.2	11.7	12.1	0.855	-	25.2	21.5	23.0	0.000*	On-T; On-F; T-F
Op 2	12.3	8.9	8.9	0.003*	On-T; O-F	23.4	21.7	23.5	0.080	On-T
Op 3	15.5	11.3	9.4	0.000*	O-F; T-F	23.2	20.3	22.4	0.018*	On-T; T-F
Op 5	15.3	13.7	13.4	0.004*	On-T; T-F	21.7	22.1	19.2	0.000*	On-F; T-F
Average	13.8	11.4	11.0	0.001*	On-F; T-F	23.4	21.4	22.0	0.000*	On-T; On-F
SD	1.8	2.0	2.2			1.4	0.8	1.9		

* p-value less than 0.05

Productivity

By converting the work element time units, including the non-productive time, to productivity values with stem volumes the productivity curves were formed for each technique for the overall data. In thinning, the productivity lines of different working techniques were very congruent with each other (Figure 4). The productivity difference between the highest, under the boom piling, and the lowest, right-angle piling, was 6.7% with the average stem size of thinnings. However, productivity values of different techniques did not differ statistically (KW, p = 0.249). In clear cutting, forward felling was 11.2% more productive than one-sided piling and 2.5% more productive than two-sided piling with the average stem size of 0.798 m^3. Although the productivity lines seemed to differ the difference was not quite statistically significant in the overall data (KW, p = 0.108).

Discussions and conclusion

In thinning, the differences in effective time consumptions between working techniques were not significant, therefore the productivities were also not significantly different. The hypothesis was that the under the boom piling would have been more produc-

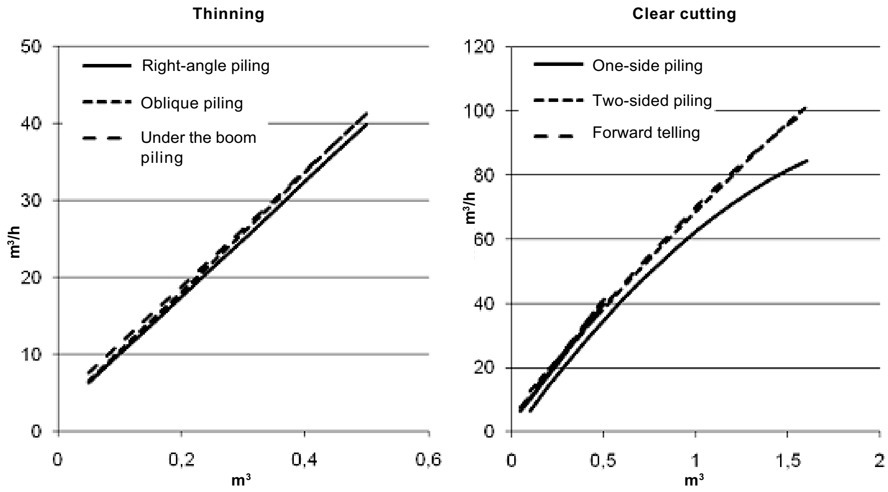

Figure 4. Effective (E_0) productivity lines for thinning and clear cutting techniques as a function of stem size processed

tive than the other techniques, which was confirmed although the difference was not significant.

In clear cutting, the most productive working technique, forward felling, was over 10% more productive than the least productive technique, one-sided piling. In addition, forward felling was 2.5% more productive than two-sided piling. The results of Nurmi (1994) support these observations since forward felling in his studies was observed to be 13-20% more productive than one-sided piling. The hypothesis was confirmed by the fact that piling on both sides the harvester is more productive than piling only to the one side.

In thinning, the moving times in different working techniques were very similar. Hence, it can be assumed that working technique hardly affects moving time. One reason could be that the harvester is located in the same working locations in the strip road regardless of the working technique. Ovaskainen et al. (2006) observed a similar locating method between different operators. However, in clear cutting using the one-sided piling working technique moving took on average less time compared to the other techniques. Assuming that the moving distance was shorter, which can be explained by the fact that the trees are felled only from one side and in front of the harvester so the number of trees felled in one working location is lower compared to the other techniques. For some reason, two of the operators moved even faster in two-sided piling than in one-sided piling. In the forward felling technique, three operators spent the most time compared to the other techniques. This is explained by the fact that the log piles need more space in the direction of the strip road when the logs are processed alongside. For this reason, the operator needs to drive forward and reverse a little when catching a tree. After finishing at the working location in this technique, the harvester is moved a considerable distance to a new working location at least the distance of the longest log so that the new piles have enough free space and the logging residues can be placed in their own pile.

In thinning, the catching spent the least time of the working techniques in oblique piling. One explanation for this is stem moving: when a tree has been moved over the strip road and processed there, the next removable tree will be taken from the processing side when the catching distance to the next tree is naturally short. It was assumed that the catching distance would have been the shortest in the under the boom piling technique since many trees are felled in a narrow felling sector there. However, after finishing the sector the harvester head must be moved to a new sector, which can result in a long catching distance. Therefore, this study does not unambiguously confirm the shortest possible catching distance for this technique. The average catching distance is short among trees in a certain sector, but the average in the working location might be longer. Another reason can be the fact that the stand was not very dense; when the number of trees felled in one sector is low and the number of sector changes in relation to felled trees is high. Instead in clear cutting, one-sided piling took the most time of the clear cutting techniques in catching, which can be explained simply by the longer catching distance always focusing on the same side of the strip road. Two-sided piling and forward felling were very similar regarding catching time consumption.

In thinning, under the boom piling technique had the lowest felling for all operators. In this technique, the stem is moved only a little from the stump so it is natural that the felling time is short. In right-angle piling, two operators had a lower time consumption compared to the oblique piling. These operators probably did not move all the stems over the strip road, instead, they processed some trees on the felling side so that the logs were at a 90 degree angle to the strip road in the felling side. In clear cutting conditions, one-sided piling had the highest felling time, which is explained by the high moving distance of trees over the strip road.

The processing was expected to be “constant”, independent of the working technique. The harvester head fed the stems automatically, stopped at cross-cutting points and the operator accepted the cross-cutting without considering its suitability. However, in thinning processing was faster in under the boom piling technique than in the other thinning techniques. In under the boom piling the operator had a good view for feeding the stem toward the boom base of the harvester, therefore, ensuring that the tree would not encounter any other remaining trees and, thereby, requiring halting of the feeding. In other feeding directions the risk of feeding the tree ahead of other trees is higher. In clear cutting, processing in one-sided piling was higher compared to the other techniques. One reason is starting of processing during the felling when part of the felling time actually belongs to processing. Another reason can be the difficulty to discern in the 3-D environment, especially depth, when piling the logs on their own assortment piles takes more time.

The study of Ovaskainen (2005) observed that discerning the stereoscopic effect of the visualized forest was more difficult than in a real harvester. For this reason, some catches did not succeed and they appeared in a form of failed catch or failed estimation of catching distance in the experiments. In this study, obvious outlier observations were removed from all the work elements. Ovaskainen (2005) also observed that the limited view of the sides of the harvester increased the reversing share in effective time consumption. In this study the operators were advised to carefully observe removable trees on the sides and use a button combination to steer only the working view to the side without steering the harvester head to the side. On the other hand, operators working techniques used in real harvester might also influence the work element times.

Ovaskainen (2005) also observed that the dynamics of moving and processing work elements in the simulator did not quite correspond with reality: they were easier to perform with a result that the time consumptions were smaller. With the real harvester moving a tree took approximately two seconds less time compared to the simulator. Since the operators used the same crane movement speed in this study, the work element times between working techniques of the operators are very comparable, thereby, enabling the determination of the true influence of the working technique because the difference is caused only by the different moving distance. As mentioned earlier, the processing was "standardized" by the fact that the harvester automatically performed everything except cross-cutting. However, it depended on the operator how quickly they accepted the suggested cross-cutting point. The mentioned stopping of feeding as a result of encountering an obstacle can also be found in real harvester work in the form of more careful feeding which increases time consumption.

In this study four operators cut one experiment with each technique on the simulator. 45 minutes as the duration of the experiment proved to be the minimum time to obtain a reliable number of felled trees. Collecting the data with an automatic datalogger avoids the partly subjective, random variation, resulting from a person collecting the data manually. In addition, downloading the same stand again to the new experiment removes a considerable amount of the variation in the circumstantial factors.

In thinning, the differences between working techniques were smaller than expected. This is mainly due to the fact that some trees are handled, independent of the technique, in the same kind of work cycles. A reason for this can be found in the limitations of the harvester crane movement created by the remaining trees. For example, Ovaskainen et al. (2004) observed that trees located far from the strip road were always felled away from the road allowing the operator to move the stem closer to the strip road. These matters equalize time consumption observations between the working techniques because the same cycles exist for different techniques. Ovaskainen et al. (2004) also observed that the largest differences in felling directions were for trees located on the strip road or on its near side area. A strong assumption is that the time consumption differences in tree cycles in different techniques are the largest for these trees. Therefore, in the case of thinning, different working techniques inevitably contain features of other techniques so locating the features of a single tree cutting into some technique is not beyond dispute.

Different working techniques have also some pros and cons from the forwarder work point of view. In the techniques were the piles will be in an right-angle to the strip road or to the harvester moving line the colour marks on the tops of the bolts are better visible to both driving directions. In thinning, the pile size is probably the smallest in under the boom piling technique because the idea is to process each tree with minimum felling move. This probably increases ordering and collecting time of bolts on the ground in forwarding. In clear cutting in techniques were bolts are piled on both sides of the strip road more space for the assortment piles are available. This can ease loading. Forward felling technique is suitable for stands when the logging residues are collected from the cutting area. Logging residues are placed to the front side of the logs.

The results of this study are promising from the productivity development point of view. However, it depends on the situation and operator when, and to what extent, the most productive working techniques are possible to use in the real work. In thinning, it is often important to deposit branches and tops of the felled trees on the strip road to decrease root damage and depressions (Eliasson and Wästerlund 2007). In under the boom piling technique all the branches and tops are not moved to the strip road. So when the snow layer is thick enough or the cutting takes place on well bearing ground this technique can be used fully. In clear cutting, the most typical technique is to make one-sided piling because of its practicality and the suitability of the harvester head. Older harvester heads were not completely suitable for two-sided processing when it was natural to process only on one side. Thus the habit of processing only on one side remains. To conclude the productivity can be easily increased especially in clear cutting conditions by choosing the most productive working technique on the basis of the stand requirements and taking into account the possibilities of the latest machine solutions.

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ПРОДУКТИВНОСТЬ РАЗЛИЧНЫХ ТЕХНОЛОГИЙ РАБОТЫ ПРИ РУБКАХ УХОДА И СПЛОШНЫХ РУБКАХ В УСЛОВИЯХ РАБОТЫ СИМУЛЯТОРА ХАРВЕСТЕРА

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Резюме

Целью этого исследования было провести сравнение продуктивности трех технологий работы в рубках ухода и трех технологий работы для сплошных рубок в условиях работы однозахватного харвестера. В большенстве случаев условия в лесу настолько разнообразные, что очень часто бывает сложно сделать достоверное сравнение результатов при рубках. Именно по этой причине эксперименты по рубкам были выполнены с использованием виртуального симулятора харвестерной машины, что позволило сделать условия эксперимента более однородными для операторов и стало возможным сопоставить результаты эксперемента. При этом одно и тоже насаждение может быть повторно загружено в систему, и рубка может выполняться с применением различными технологий, используя те же самые технические настройки столько раз, сколько необходимо для каждого опыта. Изучаемые технологии работы в рубках ухода были: складирование сортиментов под прямым углом к волоку, складирование сортиментов под острым углом к волоку и складирование сортиментов под стрелой харвестера. При сплошных рубках: складирование сортиментов с одной стороны от волока, двустороннее складирование и складирование по ходу движения харвестера. Результаты подтвердили, что в рубках ухода разница в продуктивности между наименее продуктивным (складирование сортиментов под прямым углом к волоку) и наиболее продуктивным (складирование сортиментов под стрелой) составила около 7%, и было вызвано в основном быстротой рабочей фазы - валки. При сплошных рубках уровень продуктивности складирования по ходу движения и двухстороннего складирования были одинаковы (разница около 1%). Продуктивность этих двух технологий в сравнении с односторонним складированием была выше на 11%. Разница была вызвана разницей в быстроте рабочих фаз захвата и валки дерева (около 5 секунд). Результаты являются важными с точки зрения обучения и подготовки соискателей операторов, а также для повышения навыков операторов.

Ключевые слова: сортиментная заготовка, симулятор, однозахватный харвестер, технология работы