Effects of Three Harvesting Work Methods on Harwarder Productivity in Final Felling

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During the last ten years interest in the harwarder has increased, however, studies have concentrated on effects of technical improvements on machine productivity. It has been noted that there is a large potential to increase the productivity through development of suitable work methods. To find efficient work patterns for a harwarder with a turnable loading area, three different harvesting methods were studied in final felling. Three work methods were used. Method 1: the harwarder drove backwards into the stand making a strip road, strip road trees were felled and left on the ground, on the way out of the stand the harwarder cut and processed the trees on both sides of the machine directly into the loading area. Method 2: the harwarder drove forward along the edge of the cut, cutting and processing trees directly into the loading area. Method 3: the harwarder drove forward into the stand and cut and processed strip road trees and trees standing on both sides of the machine directly into the loading area. The most efficient work method was method 2 where the productivity was 13.0 m^3 u.b. per E_0h (cubic metre under bark per effective hour). The productivities for method 1 and 3 were 12.1 and 11.9 m^3 u.b. per E_0h, respectively. In addition to work method harwarder productivity was shown to be dependent on load volume, average tree size and hauling distance. The only work elements significantly affected by work methods were processing and movement during processing. The operator had only a few weeks to get used to the machine and even less time to practise on the work methods. Thus, it is probable that the productivity for the studied methods will increase with increasing work experience. Furthermore, as only three work methods were studied, there are still untested work methods. The potential to further improve harwarder work methods is considerable.

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1 Introduction

During the last ten years the pressure to reduce harvesting costs has been high and at the same time has the area of the average clearcut on private land in Sweden decreased (The Statistical yearbook… 2002). This has increased the setup costs share of the total harvesting costs and the harwarder, a combination of a harvester and a forwarder, is seen as a way to reduce this cost as only one machine has to be moved to the site (Lilleberg 1997, Hallonborg et al. 1999). Thus, the interest for the harwarder has increased and a rapid development of the Harwarder has taken place in Sweden and Finland.

Early harwarders processed logs into piles on the ground and thereafter loaded the piles in the bunks (Lilleberg 1997). Later studies have shown that processing trees directly into the load carrier significantly improves harwarder productivity (Hallonborg et al. 1999, Hallonborg and Nordén 2000, Bergkvist et al. 2002, Wester and Eliasson 2003), as the loading element is eliminated. Furthermore according to Rieppo and Pekkola (2001), equipping harwarders with a rotating cab increase productivity in late thinnings but not in early thinnings with a small harvested mean stem. Most studies of harwarder productivity in thinning and/or in final felling have concentrated on technical aspects on and possible improvements of the machine. The work method studied has often been the one that the operator felt was appropriate for the machine. However, many authors have mentioned that there is a potential to increase harwarder productivity through an improvement of work methods (Strömgren 1999, Bergkvist et al. 2002, Wester and Eliasson 2003). Wester and Eliasson (2003) noted that harwarder performance could be improved by development of suitable work methods, and that this would give the harwarder a possibility to become an economically viable alternative to the single-grip harvester system for smaller cuttings where terrain transport distances are moderate.

In a study of the effects of a turnable loading carrier (Wester and Eliasson 2003), smaller differences than anticipated were found in clear felling as the operator changed work method in order to maximise the share of trees processed directly into the load carrier when working with the fixed load carrier. When clear felling with the fixed load carrier the operator reversed along the edge of the cut, cutting and processing as many trees as possible directly into the loading area i.e. most felling was behind and slightly on the side of the machine. When using the turnable load carrier, the operator reversed into the stand making a strip road, felling and leaving strip road trees on the ground until he estimated that he could get a full load from the trees he had passed. Thereafter he started driving forward, felling and processing the trees on both sides of the machine directly into the loading area.

Partek Forest has developed a new harwarder with a turnable loading carrier based on experiences from a prototype developed by Holmen Skog. In order to find an efficient work method in final felling for this harwarder, three different harvesting methods were defined and compared in the field.

The aim of the study was to find the most efficient work method out of the three defined methods and to describe advantages and disadvantages of the different work methods.

2 Material and Methods

The study was done in two stands with a total area of 1.8 ha. Treatments were replicated in three blocks. Block 1 was located in stand 1 and blocks 2 and 3 in stand 2. The stands enabled harvesting of three loads on the harwarder per treatment in block 1, and harvesting of two loads per treatment in block 2 and 3. In total 21 loads were studied. In both stands the terrain was even with no slope, and the overall average tree size was 0.18 m^3 u.b. (Table 1). Approximately 10 per cent of the harvested trees in stand 1 and 15 per cent of the harvested trees in stand 2 had some sort of obstacle close to the stem, which could make it difficult to position the harwarder head against the tree. The most common obstacle was undergrowth close to the tree.

The three work methods studied were; method 1, the harwarder drove backwards into the stand making a strip road; strip road trees were felled and left on the ground (Fig. 1.1a and b). On the way out of the stand the harwarder cut and

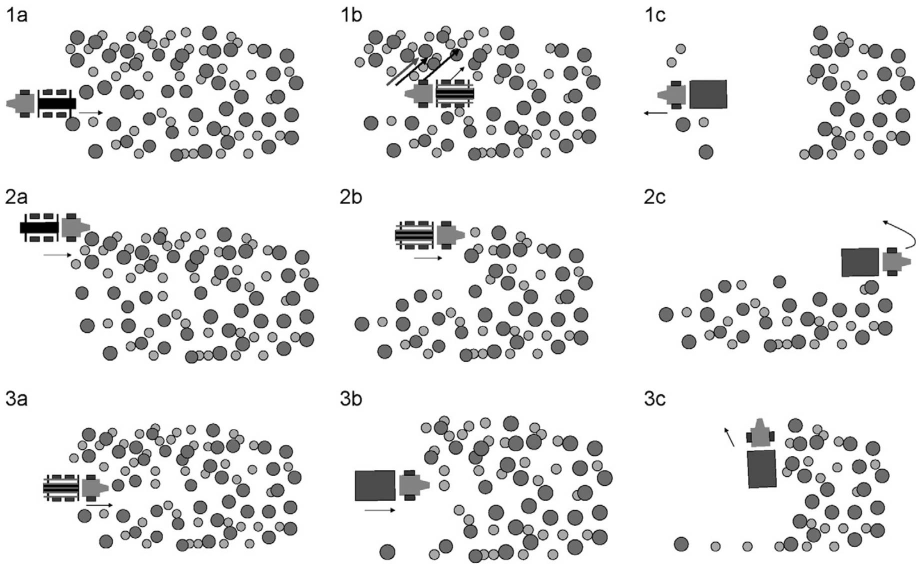

Fig. 1. The studied work methods. Method 1 (1a–c), the harwarder drives backwards into the stand making a strip road, strip road trees are felled and left on the ground. On the way out of the stand the trees on both sides of the machine are felled and processed directly into the loading area. Method 2 (2a–c), the harwarder drives forward along the edge of the cut, felling and processing trees directly into the loading area, i.e. all felling is done on one side of the machine. Method 3 (3a–c), the harwarder drives forward into the stand, felling and processing both the strip road trees and the trees standing on both sides of the machine directly into the loading area.

Table 1. Description of the test areas before felling.

	Test area 1				Test area 2			
	Pine	Spruce	Birch	Total	Pine	Spruce	Birch	Total
Tree spieces distribution %	79	18	3	100	44	37	19	100
No. of stems ha^{-1}	451	276	51	778	326	518	246	1090
Average tree diameter cm	20.7	13.4	12.5	17.5	20.3	15.1	15.8	16.8
Average tree volume [a)] m^3 u.b.	0.25	0.09	0.09	0.18	0.24	0.13	0.14	0.17
Volume [a)] m^3 u.b./ha	112	25	4	141	79	68	34	181

[a)] m^3 under bark (u.b.) calculated according to (Brandel 1990).

processed the trees on both sides of the machine directly into the loading area (Fig. 1.1c). When harvesting according to method 2, the harwarder drove forward along the edge of the cut cutting and processing trees directly into the loading area (Fig 1.2a and b), i.e. all felling was done on one side of the machine. In method 3, the harwarder drove forward into the stand and cut and processed both strip road trees and trees standing on both sides of the machine directly into the loading area (Fig. 1.3 a and b). In method 2 and 3 when the harwarder had got a full load, it left the strip road were it had been harvesting and used the adjacent strip road to travel to the landing (Fig. 1.2c and 1.3c).

The time study was done as a correlation study using snap back timing (Forest work study… 1978). It was done under daylight conditions in March 2002, using a Husky Hunter computer running Siwork3 software (Rolew 1988). The

Table 2. Work elements and their priority. If multiple work elements are performed simultaneously, time consumption was recorded for the work element with highest order of priority.

Element	Definition	Priority
Harvesting/Loading cycle		
Boom out	Starts when the combination head is moved from the harwarder towards a tree or a wood pile, ends when the head touches the tree or log pile, or when the movement stops	1
Boom in	Starts when the combination head is moved towards the harwarder empty or with a load of logs, ends when the load of logs are released, the movement stops, or when elements with higher priority starts	2
Processing	Starts when the combination head touches the tree and ends when the last log is cross-cut	1
Move	When the harwarder wheels are rolling and no elements with higher priority occurs	3
Sorting – processed in load	When the combination head is used to correct alignment of logs that have been processed directly into the load carrier	4
Cleaning	Felling of unmerchantable trees	4
Rotation of load	Rotation of the load carrier	4
Movement of load	Moving the load carrier to or from the locked position	4
Unloading cycle		
Boom out	Starts when the combination head grabs a load of logs on the load, ends when the load of logs are released on the log pile	1
Boom in	Starts when the combination head is moved towards the harwarder empty, ends when the head touches the load	1
Sorting	When the combination head is used to correct alignment of logs that have been unloaded	1
Sorting load	When the combination head is used to separate assortments on the load carrier	1
Move	When the harwarder wheels are rolling and no elements with higher priority occur	2
Other elements		
Move empty	Starts when the harwarder leaves the landing and stops when it stop to fell a tree or load logs	2
Move loaded	Starts when the harwarder wheel turns after the last stop to load or process trees and stops when it stops with the load at the landing	2
Miscellaneous	Productive work that does not belong to any element above	5
Delay	Non-productive time, not included in the analysis	5

snow depth in the two stands was on average 60 cm and there was snow in the tree crowns. During the time study the number of conversion sites were noted and after the time study machine movements lengths were measured. Harwarder work was split in almost the same 17 work elements used by Wester and Eliasson (2003). As the intention was to process all trees directly on the load carrier, sorting of loaded logs were excluded and a work element *Sorting load* added to the unloading phase as the driver was observed doing some sorting work on the load when he was unloading (Table 2). If multiple work elements were performed at the same time, the time for the work element with the highest priority was recorded. All element times were measured as effective times (E_0) (Forest work study… 1978) and although *delay* times were measured they were not included in the analysis.

For all work elements, analysis of variance and analysis of covariance in SPSS were used to detect treatment effects in element time per m^3 u.b. In the models, covariates were used when they were considered logical and not risked to be confounded with treatment effects. Tukey hsd tests were used to detect differences in treatment means. Regression analysis was used to establish a relation between influencing factors and total time per m^3 u.b. Results of the statistical analyses are considered significant if $p<0.05$.

3 Results

The most efficient work method was method 2 where the productivity was 13.0 m^3 u.b. per E_0h (cubic metre under bark per effective hour). Method 2 was significantly separated from method 1 and 3, where the productivities were 12.1 and 11.9 m^3 u.b. per E_0h, respectively.

Harwarder productivity was significantly influenced by average tree size, load size (Fig. 2) and hauling distance. Time consumption in E_0h per m^3 u.b. can be estimated by the regression:

$$T = \left(524.366 - \frac{42.393}{\bar{v}} - 21.701V_L + 0.211D_L - 10.357M_1 - 30.249M_2 \right) / 6000$$

where $\bar{v}$ is average tree size in m^3 u.b., V_L load size in m^3 u.b., D_L hauling distance with load in m, and M_1 and M_2 are dummy variables for method 1 and 2. These dummy variables get the value 1 for the method used, if both M_1 and M_2 are 0 it is assumed that method 3 is used. The model has an adjusted R^2 of 0.939, 13 degrees of freedom for error and the p-values for the parameters are <0.001, <0.001, <0.001, 0.016, 0.354 and 0.024 for the constant, $1/\bar{v}$, V_L, D_L, M_1 and M_2, respectively.

Significant differences between the three work methods were only found for the work elements *Processing* and *Move* in the harvesting loading

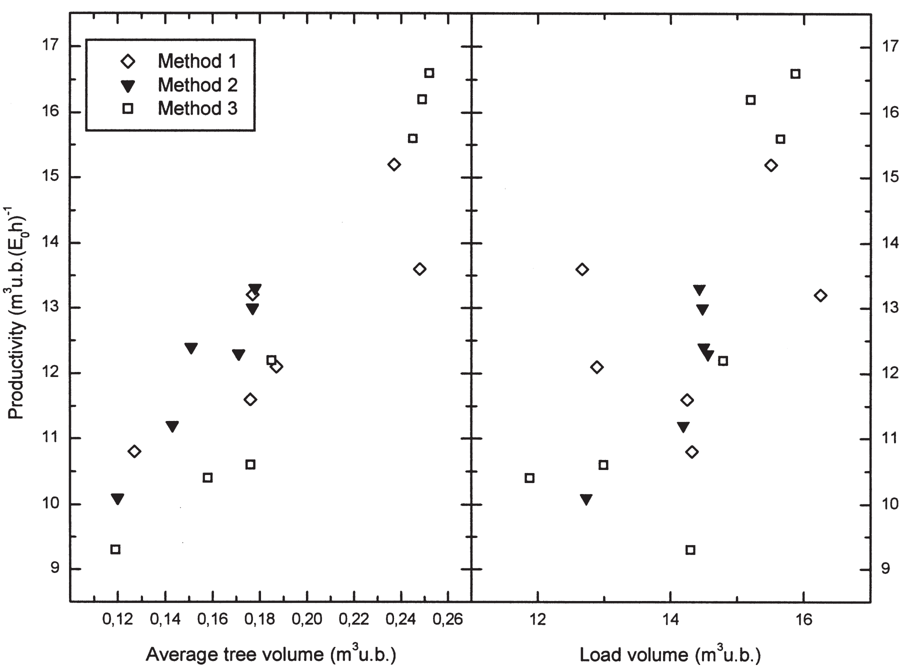

Fig. 2. Observed harwarder productivity for each load versus average tree volume and load volume.

Table 3. Corrected mean times per method and work element (cmin/m^3 u.b.). Work element mean times followed by different letters were significantly separated ($p < 0.05$)

Work element	Method 1	Method 2	Method 3	Covariate
Move empty	23a	19a	22a	Hauling distance empty
Move loaded	27.0a	28.4a	29.0a	Hauling distance loaded
Harvesting/loading cycle				
Boom out	73a	72a	81a	No of trees (m^3 u.b.)$^{-1}$
Boom in	0.5a	1.5a	1.1a	
Processing	203a	183b	212a	Average tree volume
Rotation of load	7.6a	7.1a	7.8a	
Move	40a	38ab	27b	
Sorting – processed in load	7.6a	7.7a	10.7a	
Cleaning	14.0a	16.6a	18.4a	
Movement of load	3.4a	3.1a	2.6a	
Unloading cycle				
Boom out	44a	50.2a	46.3a	
Boom in	23.5a	26.6a	27.3a	
Move	7.5a	9.6a	8.0a	
Sorting	2.6a	4.2a	4.3a	
Sorting load	1.7a	2.5a	3.5a	
Miscellaneous	0.8a	0.6a	1.5a	

Table 4. Levels of significance (p-values) from the analyses of variance of the element time consumptions per m^3 u.b. (cmin/m^3 u.b.). Error DF = 18 for models with no covariate and 17 if a covariate was used.

Work element	Method	Block	Covariate
Move empty	0.326	0.858	0.047
Move loaded	0.356	0.233	0.047
Harvesting/loading cycle			
Boom out	0.196	0.025	<0.001
Boom in	0.628	0.210	
Processing	0.014	0.055	<0.001
Rotation of load	0.854	0.154	
Move	0.025	0.455	
Sorting – processed in load	0.406	0.087	
Cleaning	0.865	<0.001	
Movement of load	0.648	0.457	
Unloading cycle			
Boom out	0.196	0.068	
Boom in	0.187	0.808	
Move	0.480	0.250	
Sorting	0.703	0.232	
Sorting load	0.466	0.716	
Miscellaneous	0.580	0.204	

cycle (Table 3 and 4). The largest difference between work methods was found for *processing* were method 2 was approximately 10 per cent faster than the other methods. Harvesting swaths were 65 m for method 1, 133 m for method 2, and 51 m for method 3. Due to the method, the harvesting swath was travelled twice in method 1 making the travelled distance 130 m per load during the harvesting/loading cycle. On average, the distance travelled without load was 180 m and the distance travelled with load was 185 m.

4 Discussion

The operator in this study, an experienced harvester operator, had only a few weeks to get used to the machine and even less time to practice on the work methods. Thus, it is probable that productivity for the methods studied will increase with increasing work experience. The three work methods were chosen based on experiences from earlier studies (Strömgren 1999, Wester and Eliasson 2003) and on what the operator thought feasible. However, as only one operator was studied there is a risk that the results could be different for other operators. Thus, under different conditions other work methods could not only be a feasible alternative but even superior to the studied methods. For instance in stands with established strip roads at a spacing smaller than the double length of the boom some kind of a double sided variant of method 2 could be efficient, i.e. that the harwarder drives forward in the strip road processing trees directly in the loading area from both sides. Thus, there still is a large potential to improve harwarder work methods.

Although, the objective of the present study was not to find a general productivity level for the harwarder and the material is too limited to do so, some comparisons can be done with previous studies. The productivity when using method 2 in this study is approximately 10 per cent higher than the productivity recorded by Wester and Eliasson (2003) when the same work method was used by a prototype harwarder, with the same type of load carrier. That study was done in a denser stand with larger trees but with slightly more difficult terrain. The productivities in the present study are also high compared to the productivity figures in a larger follow-up study of harwarders made by Sirén and Aaltio (2003), however the transport distances were longer in that study.

The differences between work methods were found in elements belonging to the harvesting/loading cycle, indicating that the studied work methods did not influence sorting and separation of assortments to any larger extent. Thus, work methods did not influence the unloading cycle.

One of the drawbacks with method 1 and 3 was that if the operator underestimated the distance between the edge of the cut and the strip road he made to enter the stand, some trees at the cut edge became out of reach for the boom. In order to harvest these trees it became necessary to move the machine and this took some time. Method 1 and 3 would probably be more efficient in stands with fewer stems per hectare compared to the stands in the present study. In a stand with a small number of stems per hectare it would be easier to drive at an optimal distance from the stand border, and thus minimize the risk for extra work in order to harvest unreachable trees. Furthermore, few trees have to be cut when the machine enters the stand and that reduces the amount of long boom movements and/or wood processed on the ground.

The strength of method 2 may be that processing into the loading area starts directly when the harwarder comes to the stand border, e.g. there is no time for entering the machine into the stand. Another advantage of method 2 was that it eliminated the risk for trees in the edge of the cut to be out of reach. A disadvantage was that the loading area had to be rotated 180 degrees a number of times during the processing to prevent that the load started to slope. No significant differences in time for rotating the loading area were found between methods during the study.

As the regression shows, harwarder productivity was dependent on load volume, average tree size and hauling distance. However, load volume and average tree size was positively correlated, i.e. harvesting of larger trees gave larger loads. This was partly caused by the fact that the proportion between solid wood volume and piled wood volume increases with tree size, thus, two loads that have the same piled volume on the load carrier might have different volumes of solid wood. The maximum load volume of the machine was approximately 16 m^3 u.b., and the actual load volume ranged from 11.9 to 16.25 m^3 u.b. The correlation between load volume and average tree size makes it difficult use the regression to generalise the results.

Other methods for final felling will probably be developed, and the three methods in the study can also be combined to fit other types of stands and situations. This study showed that harwarder productivity could be significantly increased if the right work method was applied. It is important that evaluation and testing of work methods are continued for this new machine, not only in final felling but also in thinnings, in order to use it as efficiently as possible.

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