Productivity in Final Felling and Thinning for a Combined Harvester-Forwarder (Harwarder)

Fredrik Wester
Martinsson AB
Bygdsiljum, Sweden

Lars Eliasson
Swedish University of Agricultural Sciences
Umeå, Sweden

ABSTRACT

During the last decade, the interest for a combined harvester forwarder (Harwarder) has increased and a quite rapid machine development has taken place in the Nordic countries. In 2000 a new prototype equipped with a rotatable and tiltable load carrier was built in order to enhance the possibilities for processing logs directly into the load carrier. A time study was done to test the hypotheses that 1) the rotatable and tiltable load carrier decreases total time consumption, and thus increases productivity, compared to a fixed load carrier, and that 2) the difference in time consumption between the two harwarder configurations is larger in final felling than in thinning. Results showed that harwarder productivity was increased by 6 per cent in final felling and 20 per cent in thinning by the introduction of a rotatable load carrier. In final felling with the fixed load carrier, the operator changed work method in order to process as many trees directly into the load carrier. It is suggested that this explains why the difference between machine configurations was lower for final felling than for thinning. Calculated harvesting costs for the harwarder were higher than the expected harvesting costs for a harvester and a forwarder in the studied stands. However, there is a large potential to increase harwarder productivity by both further development of the machine and the work methods used.

Keywords: *harvesting, cut to length.*

INTRODUCTION

Since the start of mechanisation one of the dreams has been a machine that can perform all work tasks of the harvesting process. One of the first machines that managed to do this was the Bush Combine of the late fifties. However, as the later Koering shortwood harvester the Bush Combine was limited to producing fixed length pulpwood bolts, and thus, was not adapted to harvesting stands where wood has to be separated into multiple assortments with different log lengths [11]. In the Scandinavian countries experiments with machines that could do both the work of a harvester and a forwarder started shortly after the introduction of the single-grip harvesting head. In the late eighties and early nineties the first tests of these machines showed a low productivity in the harvesting phase [1, 9]. In 1997, the concept started to take shape and at the Elmia wood trade fair that year, both Hemek and Pika presented prototypes and Sydved presented a vision of a machine that processed the logs directly into the load carrier of the machine. These machines that are a combination of a harvester and a forwarder, were called Harwarders. Both the Hemek and Pika prototypes were forwarders that had been equipped with a combination head that could be used as both a single-grip harvesting head and a grapple. When trees were felled they were processed into piles on the ground that were then loaded on the load carrier.

In 1996 a modified Hemek forwarder, equipped with a Pogen 1.0 combination head, was studied in both thinning and final felling providing productivities of 7.5 and 11.6 m^3 under bark per effective hour (m^3u.b./E_0h), respectively [5]. In a study of the Pika machine in first thinning a productivity of 4.8 m^3/E0h was obtained [8]. However, the trees harvested were smaller than in the Hemek study, which partly explains the lower productivity. In 1998 a new study was made of the Hemek machine previously studied by Cederlöf [5]. During the two year interval since Cederlöf's study, several modifications had been made to the machine, however, machine productivity had not increased [12]. Furthermore, this study showed that the studied combination head was slower at delimbing and crosscutting than a single-grip harvester head, and that this was more pronounced for spruce trees. Although not explicitly studied, processing directly into the load carrier was seen as a way to increase harwarder productivity.

In 1999 Skogforsk and Sydved carried out a trial with a Valmet 911 harvester equipped with a trailer and a modified Pogen combination head. The machine, which cut and lifted the standing trees to a position behind the trailer where it felled them and processed them directly onto the trailer, produced 4.8 - 5.2 m^3u.b./E_0h in thinning [6]. The work pattern resulted in minimal damage to residual trees and most slash was placed in the strip roads. In 2000 a new approach to direct loading was taken when a Hemek harwarder was equipped with a rotatable and tiltable load carrier and a harvester boom in order to enable processing into the load carrier without the need to process the trees

The authors are, respectively, Forester, Martinssons AB, and Researcher, Department of Silviculture, Swedish University of Agricultural Sciences.

behind the trailer part of the machine. The idea was that the load carrier should be rotated towards the tree to be felled, so that the boom only had to pull the tree towards the machine and process it directly into the load. However, this solution is better adapted to final felling than thinning as the possibilities to rotate the load carrier are reduced by residual trees in thinning. Thus, the proportion of trees processed directly into the load carrier would be lower in thinning than in final felling.

Our hypotheses were that 1) the rotatable and tiltable load carrier decreases total time consumption, and thus increases productivity for the harwarder compared to a fixed load carrier, and that 2) the difference in time consumption between the two harwarder configurations is larger in final felling than in thinning.

MATERIAL AND METHODS

The experiment was designed as a 2x2 factorial with the factors being machine configuration (rotateable vs. fixed load carrier) and cutting type (final felling vs. thinning). The study was done in two stands at the village Södra Lidträsk, 30 km SE of Norsjö in the province of Västerbotten, Sweden. The final felling stand was spruce dominated (80% Norway spruce (*Picea Abies* (L.) Karst.), 1% Scots pine (*Pinus Sylvestris* L.), 19% Birch (*Betula* sp.)) and situated on mesic till soil with some small wet peaty spots in a gentle slope with a few rocks on the ground. The thinning stand consisted of a pine overstory and a mixed spruce birch understory (Table 1). The two stands had similar terrain, both being classified as category 2.2.1 according to the *Forskningsstiftelsen Skogsarbetens* classification system [3]. The ground was wet, due to a rainy summer and fall, and during the study it rained approximately 40 per cent of the time.

In the final felling stand, stem diameter at breast height (dbh) was measured and marked on all trees, and the height was measured on every 20th tree. On ten 10 m radius sample plots in the thinning stand, all trees were marked and their diameter measured, and the height of every seventh tree was measured.

In accordance to standard practice, the harvester operator selected which trees to harvest in the thinning (c.f. [13]). As the thinning stand was previously thinned, the machine operator was instructed to use the old strip roads as much as possible. Furthermore he was instructed to thin from below, i.e. to first remove strip road trees and defect trees and then to select sub- and co-dominant trees until 35 per cent of the basal area was removed (c.f. [7]). In both stands the harvested trees were cut and sorted into four assortments, spruce sawlogs, pine sawlogs, softwood pulpwood, and hardwood pulpwood.

The studied harwarder was a modified Hemek forwarder equipped with a modified Pogen 1.0 combination head (grapple/harvester head) mounted on a 9.0 m reach FMG185 two-grip harvester boom. During April, 2000, the ordinary fixed load carrier on this machine was replaced with a load carrier situated on a turntable that could be tilted.

Table 1. Description of treatment plots before logging, and of trees extracted. Values given are mean values per hectare.

	Before treatment				Extracted			
	Trees	dbh (cm)	Volume (m^3)[a]	Mean stem volume (m^3)[a]	Trees	dbh (cm)	Volume (m^3)[a]	Mean stem volume (m^3)[a]
Final felling	936	18.2	208	0.22	928	18.2	206	0.22
Pine	6	16.8	2	0.26	6	16.8	2	0.26
Spruce	756	18.3	174	0.23	755	18.3	173	0.23
Birch	174	18.3	33	0.19	167	17.7	30	0.18
Thinning	1019	15.1	141	0.14	568	12.9	52	0.09
Pine	223	19.9	56	0.25	106	17.4	20	0.19
Spruce	584	14.8	69	0.12	318	12.0	23	0.07
Birch	212	11.8	15	0.07	143	11.5	9	0.06

[a] m^3 under bark (u.b) calculated according to Brandel [4]

The study was done as a correlation study with snap back timing [2] under daylight conditions in October 2000, using a Husky Hunter computer running Siwork3 software [10]. Although it rained, visibility was good and there was almost no wind. During the time study the number of stops for felling, processing and loading were noted. After the time study machine movement lengths were measured. Harwarder work was split into 17 work elements (Table 2). If work elements were performed simultaneously, the time for the work element with the highest priority was recorded. All element times were measured as effective times (E_0) [2]. Delay times were measured but not included in the analysis.

Table 2. Work elements used in study. Note: if multiple work elements are performed simultaneously, time consumption was recorded for the one with highest 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
Sorting – loaded logs	When the combination head is used to correct alignment of logs that have been loaded from the ground	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
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

Element times were summarised for each load, and recalculated to cmin per m^3 u.b. in order to remove effects of differences in volume between loads. For all work elements, analysis of variance, using a general factorial model in SPSS, was used to detect treatment effects in element time per m^3 u.b.. To correct for differences in distance travelled, differences in tree sizes and differences in proportion of trees processed into the load carrier, the covariates distance travelled per m^3u.b., number of trees per m^3u.b and estimated number of boom movements were used in the model where appropriate. Student's t-tests were used to detect effects of machine configuration in each cutting type. Results of the statistical analyses were considered significant if $p<0.05$.

RESULTS

The observed productivities were 10.9 m^3u.b. per effective hour (E_0h) with the rotatable load carrier and 10.3 m^3u.b./E_0h with the fixed load carrier when clear-felling and 6.0 and 5.0 m^3u.b./E_0h respectively when thinning. The productivity difference in clear-felling was not significant, but differences when thinning and between thinning and clearfelling were. Most of the time (70 to 80 per cent) was spent on harvesting and loading (Table 3). The rotatable load carrier decreased the time consumption for the harvesting and loading cycle, mainly because of the reduction of *boom in* movements (Table 3). Unloading was however significantly faster from the fixed load carrier (Table 3 and 4).

The reductions in time consumption, during the felling and processing cycle, for *boom out* and *boom in* when using the rotatable load carrier were probably caused by the reduced number of boom movements when processing the wood into the load. This is supported by the fact that the introduction of a estimated number of boom movements as a covariate in the model removed both the significant treatment interaction and the significant effect of machine configuration.

The machine operator varied his work pattern in order to process as many trees as possible on the load carrier.

Table 3. Observed mean work element time (cmin/m^3ub) per treatment.

	Final felling		Thinning	
	Fixed load	Rotatable load	Fixed load	Rotatable load
Move empty	21.1	24.3	47.8	20.5
Move loaded	30.0	26.7	42.5	30.4
Harvesting/Loading				
Boom out	69.8	62.3	213.4	138.4
Boom in	21.2	1.8	164.7	23.5
Processing	254.8	256.3	360.0	412.3
Move	59.4	34.7	155.2	137.1
Sorting – processed in load	5.8	6.3	0.4	8.9
Sorting – loaded logs	5.4	0.0	18.8	2.9
Cleaning	10.6	10.0	13.0	19.8
Rotation of load		8.6		41.9
Movement of load		6.2		4.2
Total Harvesting/Loading	427.0	386.2	925.5	789.0
Unloading				
Boom out	39.9	42.6	52.0	59.8
Boom in	17.3	20.6	24.5	26.9
Sorting	9.5	12.0	12.6	21.7
Move	13.8	16.7	5.2	6.4
Total Unloading	80.5	91.9	94.3	114.8
Miscellaneous	23.8	20.1	95.2	41.4
Total effective time	582.4	549.2	1205.3	996.1

Table 4. Anova p-values, error DF=26 for models with no covariate and 25 if a covariate is included in the model.

	Machine configuration (M)	Harvesting type (H)	M*H	Covariate p	Covariate used covariate
Move empty	0.169	0.163	0.006	0.001	distance travelled per m^3u.b.
Move loaded	0.473	0.87	0.931	0.000	distance travelled per m^3u.b.
Harvesting/Loading					
Boom out	0.000	0.000	0.000		
Boom in	0.000	0.000	0.000		
Processing	0.013	0.380	0.007	0.000	number of trees per m^3u.b
Move	0.009	0.000	0.667		
Sorting – processed in load	0.015	0.438	0.030		
Sorting – loaded logs	0.000	0.000	0.015		
Cleaning	0.383	0.098	0.301		
Rotation of load		0.000			
Movement of load		0.187			
Unloading					
Boom out	0.063	0.000	0.357		
Boom in	0.038	0.000	0.746		
Sorting	0.015	0.009	0.157		
Move	0.355	0.000	0.697		
Miscellaneous	0.001	0.000	0.004		

When final felling he managed to process 83.5 per cent of the trees into the load while working with the fixed load carrier and 98.4 per cent while working with the rotatable load carrier, in thinning the corresponding figures were 14.3 and 88.2 per cent.

In the thinning treatments 7 per cent of the residual stems were damaged when the fixed load carrier was used and 8 per cent when the rotatable load carrier was used. The difference was not significant.

DISCUSSION

In this study, harwarder productivity was increased by 6 per cent in final felling and 20 per cent in thinning by the introduction of a rotatable load carrier. This means that we could reject our null hypothesis that the two machine configurations were equally efficient. However, as the increase in productivity was larger in thinning than in final felling the null hypothesis was rejected but not for the expected reason. One of the probable explanations for the fact that the difference between machine configurations was lower for final felling than for thinning was the large share of trees processed directly into the load carrier when final felling with the fixed load carrier. The operator managed to get a high share of processing into the load carrier through a decrease in the swath width so that most trees were felled behind the machine, the trees could then be processed into the fixed load carrier. However, this change of the working method increased the length of the harvesting swath in order to fill the load carrier and thus the move time during harvesting and loading increased.

The machine studied was a prototype and had been rebuilt a number of times, the last major changes in the machine, including the installation of the rotatable load carrier, being made just a few months prior to the study. Thus the machine operator had not had the chance to try out a range of work methods, but had found one that worked for him. Compared to this study, harwarder performance can probably be significantly improved by development of suitable work methods. A better separation of the assortments in the load when the wood was loaded from the ground than when it was processed directly into the load, probably contributed to the differences found between machine configurations in element times during the unloading phase.

Significant interactions between treatments occurred for *move empty* and a number of elements in the harvesting loading phase. The *move empty* time consumption in the area thinned with a fixed load carrier was high due to a part of the trail travelled empty having a lower ground bearing capacity. This also resulted in some extra maintenance work on that part of the trail, which explains the increase in the element *miscellaneous*. During the harvesting loading phase, interactions occurred due to larger differences between machine configurations in thinning compared with those in clearcut. This was partly due to a large proportion of processing into the load carrier when final felling, irrespective of load carrier configuration.

Assuming a machine cost of 87 US$/$E_{15}$h if the harwarder is used 2120 E_{15}h per year [14], harvesting costs for the harwarder with rotatable load carrier were 9.25 and 16.7 US$/$m^3$ in final felling and thinning, respectively. This is more than the expected costs of 6.8 and 14.2 US$/$m^3$ respectively, for a harvester and a forwarder in the studied stands according to productivity standards [14]. Taking into account the costs of moving a machine to a new cut (215 US$ per machine), the harwarder can be seen as a profitable alternative for small final fellings (<87 m^3) and thinnings (<87 m^3). Increasing the machine utilisation will decrease harwarder costs and increase the break-even point in harvested volume. Furthermore, as there still is a large development potential both on machine and work methods, it is probable that the setup size when the harwarder will break-even with a single-grip harvester system will increase. However, for operations with long terrain transports harwarders will continue to be an uneconomical solution as a harwarder costs 30 to 40 per cent more per hour and does not load more or drive faster than a forwarder. This means that the harwarder has a possibility in the near future to become an economically viable alternative to the single-grip harvester system for smaller set-ups with short to moderate terrain transport distances. The rotatable load carrier significantly increased harwarder productivity and this increase was large enough to more than cover the expected increase in investment costs on a serial built machine. However, the machine becomes more complex with a rotatable load carrier , which may affect the long term reliability.

AUTHOR CONTACT

Lars Eliasson can be reached by e-mail at --
Lars.Eliasson@ssko.slu.se

REFERENCES

[1] Andersson,G. 1989. Kombinationsmaskin skördare-skotare – en ny maskingeneration. [Combination-machine Harvester-Forwarder – a new machine generation] Forskningsstiftelsen Skogsarbeten, Kista, Sweden. Resultat 4. 4 pp.

[2] Anon. 1978. Forest work study nomenclature. The Nordic Work Study Council, NISK, Boks 61, 1432 Ås, Norway. ISBN 82-7169-210-0. pp. 81-99.

[3] Berg, S. 1982. Terrängtypsschema för skogsarbete. [Terrain classification for forestry work] Forskningsstiftelsen Skogsarbeten, Kista, Sweden. Handledning 28 pp.

[4] Brandel, G. 1990. Volymfunktioner för enskilda träd. Tall, gran och björk. [Volume functions for individual trees, Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) and birch (*Betula pendula* & *Betula pubescens*).] Dept. of Forest Yield Research, Swedish University of Agricultural Sciences, Garpenberg, Sweden. Report 26. ISBN 91-576-4030-0. 183 pp.

[5] Cederlöf, O. 1997. Tidsstudie av en kombinationsmaskin skotare-skördare. [Time study of a combined harvester-forwarder.] Swed. Univ. Agr. Sci., Forest Technology Section, Umeå, Sweden. Student's reports 1. M.Sc. Thesis. 21 pp.

[6] Hallonborg, U., S. Bucht, and S. Olaison. 1999. Nya grepp i gallring – "Sluten Upparbetning" minskar skadorna och ökar produktiviteten. [A new approach to thinning: Integrated off-ground handling reduces damage and increases productivity.] Skogforsk, Uppsala, Sweden. Resultat 23. 4 pp.

[7] Lageson, H. 1997. Effects of thinning type on the harverster productivity and on the residual stand. J. For. Eng. 8(2): 7-14.

[8] Lilleberg, R. 1997. Harvester-forwarder for logging in first-thinning stands. Metsäteho, Helsingfors. Report 28. 24 pp.

[9] Pedersen, J. 1995. Kombinationsmaskin skördare skotare. Studie av en prototyp FMG250 / Timberjack DA-90. [Combination-machine Harvester-Forwarder. study of a prototype FMG250 / Timberjack DA-90.] Skogforsk, Uppsala, Sweden. Stencil. 28 pp.

[10] Rolew, A.-M. 1988. Siwork 3, version 1.1. Work study and field data collection system based on Husky Hunter handheld computer. Danish Forest and Landscape Research Institute, Lyngby, Denmark. 35 pp.

[11] Silversides, C.R. 1997. Broadaxe to flying shear: The mechanization of forest harvesting east of the Rockies, National museum of Science and Technology, Ottawa, Canada. ISBN 0-660-15980-5. 174 pp.

[12] Strömgren, A. 1999. Drivare. Produktivitet och ekonomi i gallring och slutavverkning. [Productivity and economy in thinning and final felling for a combined Harvester-Forwarder.] Swed. Univ. Agr. Sci., Forest Technology Section, Umeå, Sweden. Student's reports 23. M.Sc.Thesis. 27 pp.

[13] Suadicani, K. and T. Nordfjell. 2003. Operational aspects of row and selective thinning in the establishing of a shelterwood in a 50-year-old Norway spruce stand. Int. J. For. Eng. 14(1): 25-37.

[14] Wester, F. 2001. Kostnad och prestation för en ny typ av drivare. [Productivity in thinning and final felling for a new type of combined harvester-forwarder.] Swed. univ. agr. sci., section of forest technology, Umeå, Sweden. Student's reports 47. M.Sc. Thesis. 29 pp.