THINNING WITH THE VALMET 500T STEEP-TERRAIN HARVESTER

Raffaele Spinelli* and Bruce Hartsough**
*CNR – Timber and Tree Institute
Via Madonna del Piano – Palazzo F, I-50019 Sesto Fiorentino (FI), Italy
**Biological and Agricultural Engineering
University of California
One Shields Avenue, Davis, CA 95616, USA
spinelli@ivalsa.cnr.it; brhartsough@ucdavis.edu

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Abstract: *CTL technology offers the benefits of limited environmental impact, simpler logistics and increased operator comfort. Its application to mountainous terrain relies on self-leveling carriers, like those developed in Central Europe and North America. The authors studied one such machine - a Valmet 500T – as it was used for thinning both a natural stand and a young plantation on steep terrain. The plantation was much more difficult to harvest, due to the thick undergrowth and persistent lower branches on the trees. Productivity was further limited by the very small tree size. Nevertheless, the working pace of the machine is very fast, which helps when processing small trees. This allows for a good productivity level when harvesting trees delivering at least 0.25 m^3 of logs. Much below this threshold, productivity drops more substantially.*

1. Introduction

Cut-to-length (CTL) harvesters are sophisticated and expensive machines. Ideally, a sophisticated machine should operate within its own range of optimum working conditions, and if it is expensive it should also maintain a high annual output. Aiming to increased diversity, modern silviculture can hardly offer such ideal working conditions. This results in an eclectic use of forestry equipment, which is often pushed far beyond its optimum working range. In order to accumulate a sufficient annual output, forest machines are increasingly taken to inaccessible sites and into a number of different stands. The flexible use of modern CTL harvesters is just one more episode of this general trend. Originally designed for clearcutting uniform stands in even terrain, harvesters are now used to selectively thin many forest types under varied terrain conditions - including steep slopes.

Of course, harvester manufacturers have made their adjustments, and they now produce special models that are designed to negotiate rugged terrain and handle difficult trees. American loggers have successfully introduced CTL harvesting to steep country, where they use specialized self-leveling carriers. Their European colleagues have already pushed the standard rubber-tired harvester to its slope limit, and are ready to take the following step. At present, a few self-leveling tracked carriers operate in the Old Continent, and their number might increase very rapidly. Therefore, any additional information is extremely valuable.

Carried out in America, this study aims to provide more hard data on the performance of a self-leveling harvester when used for the selective thinning of two different stand types under variable terrain conditions. The machine selected for the study is a Valmet 500T - a best seller in America and an interesting mix of American and European technology. Indeed, the Valmet 500T joins one of the best American self-leveling carriers to a widely appreciated European harvester head. The match seems ideal, and it must be very good if it can cope with the hard working conditions of the American mountain forests.

2. The Valmet 500T

The Valmet 500T is a purpose-built harvester, especially designed for steep-terrain operations. It consists of a heavy-duty Caterpillar 325 undercarriage, connected to the main rotating platform through a self-leveling joint. The platform can tilt 27° to the front, 7° to the rear and 20° on both sides. The platform carries a 126-kW Cummins engine, a sturdy safety cab and a Cranab 1400 two-stage telescopic boom. A Valmet 965 harvester head is mounted at the end of the boom. This is a European-style dangle head with 5 limbing knives and a hydraulic chainsaw. The chainsaw has a 75 cm bar and can cut a maximum diameter of 63 cm. Two hydraulically driven feed rollers propel the stem through the knives. Each roller is powered by a 918 cm^3 radial piston motor, producing a tractive force of 24.5 kN. The rollers are made of solid rubber in order to prevent fiber damage. Wrapping the rollers with basket chains increases adherence. The Finnish manufacturer designed the 500 T especially for the American market. Compared to European rubber-tired harvesters, the 500T is more compact and can negotiate steeper slopes. It has become a favorite of American loggers and is Valmet's best-selling harvester in the West. A description of the machine is provided in Table 1.

Table 1: Machine description

Carrier	type	Valmet 500T
Configuration		Tracked self-leveling
Undercarriage		Caterpillar 325 (D6)
Approx. Weight	kg	21,500
Engine		Cummins 6BTA 5.9 lt. Turbo
Power	kW	126@2100 rpm
Width	cm	290 (610 mm tracks)
Length	cm	437
Height	cm	376
Ground clearance	cm	66
Head	type	Valmet 965
Approx. Weight	kg	1,150
Max cutting capacity	cm	63
Sawbar	cm	75"
Feed-rollers	n.	2
Feed-rollers	type	Solid rubber w/ basket chains
Knives	n.	5
Hydraulic requirements	l/min	260
Hydraulic requirements	MPa	24

3. Materials and methods

The authors carried out a time-motion study, designed to evaluate machine productivity and to identify those variables that are most likely to affect it. Cycle times were split into a number of time elements considered as typical of the working process. Time elements were recorded with a Husky Hunter hand-held field computer running Siwork3 timestudy software. The Siwork-equipped Husky Hunter is among the most widespread tools for studying work routines in forestry, being rugged, accurate and reliable.

Daily output was estimated by measuring a sample of logs from the amount produced each day. Total length and mid-diameter were used to calculate log volume. The sample would include batches of large sawlogs, small sawlogs and pulpwood, separated by species. Species separation was necessary because different species were cut to different measures. The daily sample would be applied to the log count of that day only, in order to compensate for variations in the specific characteristics of the stand portion harvested that day, as well as for possible errors in the recorder's identification of the assortments - which had to be done visually.

Individual trees were assigned a branching class, meant to reflect the density and dimension of their limbs (Table 2). The observer visually estimated the two characteristics. Discrete branching coefficients have been used in other studies concerning CTL harvesters (Emeyriat et al., 1997; Raymond et al., 1988).

Table 2: Branching class – definition and distribution in our sample

Class	Branch density	Max. branch Diam (at the trunk)	Frequency % (sample 1065 trees)	Frequency % (sample 415 trees)
			Natural forest	Plantation
1	light	< Diam 5 cm	14.5	1.2
2	dense	< Diam 5 cm	37.6	66.7
3	light	≥ Diam 5 cm	29.3	23.1
4	dense	≥ Diam 5 cm	14.8	4.6
5	malformed		3.8	4.4

The machine selected for the study belonged to a local firm that had used it for about two years. During the study, the company was operating in the Stanislaus National Forest, near Cabbage Patch, Alpine County, California. A Valmet 862 six-wheeled forwarder moved the logs to roadside. The whole operation consisted of two machines only - the harvester and the forwarder - that were able to maintain a balanced working pace. The harvester-forwarder system offers simple logistics and reduced moving costs. During the trials, the company harvested two different stands at an altitude of about 2,070 m asl.

The first stand was a naturally regenerated, high-elevation mixed-conifer forest. True firs constituted the main species, accompanied by dominated incense cedar. Sugar pines were also present in very small numbers. The stand had received an irregular clearcut 97 years earlier. At the time, loggers left behind a number of large trees, together with much harvesting residue, still littering the forest floor. Tall stumps and large decaying logs often hindered the advance of the harvester, which had to move them with its harvester head or turn around. Slopes averaged 30%, with peak values of 57%. The current operation aimed at reducing fuel build-up and consisted of an intense low thinning. This followed a selective criterion, whose goal was to maintain 5 m between the drip lines. The Forest Service had marked all removal trees above 30 cm DBH, but the operator was free to choose among the smaller ones. The thinning removed two thirds of the trees and about one third of the basal area. Removal tree size averaged 0.39 m^3 for the firs and 0.23 m^3 for the cedars.

The second stand was a 23-year old Ponderosa pine plantation, divided in two strips, placed inside the larger natural stand. Both strips had the same density and age, but one was much more developed than the other. This had a closed canopy, which limited weed presence of thick buckthorn (Ceanothus cuneatus) pillows. On the contrary, the other strip was much thinner and invaded by competing young fir and cedar. Slopes averaged 19%, with maximums around 40%. Removal tree size was 0.14 m^3 for the pines and 0.23 m^3 for the merchantable invading firs and cedars. A description of both stands is provided in Table 3.

Table 3: Stand composition before and after the treatment

	Naturally regenerated forest - 97 years				Plantation - 23 years			
	Trees/ha	BA m^2/ha	% BA	DBH cm	Trees/ha	BA m^2/ha	% BA	DBH cm
	Before				**Before**			
All	455	54.1	100.0	34.0	893	32.0	100.0	20.1
Firs			47.2				4.7	
Cedar			41.1				0.9	
Pine			11.7				94.4	
	After				**After**			
All	156	36.5	100.0	52.8	471	14.9	100.0	18.3
Firs			53.4				8.4	
Cedar			32.5				2.0	
Pine			14.1				89.6	

The thinning removed about half of the trees and basal area. The harvester operator would choose removal trees. He would pick defective, undersize specimens in the richer strip - but could not perform as well in the poorer one, where removing only the smallest trees would have seriously jeopardized the productivity of his machine.

The study lasted 5 days, 9-13 August 1999. The machine was operated by its owner, an experienced driver who had used it for the last two years. Previously, he had operated stroke delimbers, self-leveling feller-bunchers and another CTL harvester. He also performed all maintenance and most repairs. He had a full perception of the machine capabilities and a clear understanding of the goals that the treatment was to achieve. A study outline is shown in Table 4.

The standard routine would develop as follows. The operator would harvest parallel strips, about 15 m wide. He would proceed uphill, starting from the road and going all the way to the ridge. After he had reached the top boundary, the operator would track his way back to the road without harvesting. On his way, he would move aside old logs, crush decaying stumps and eliminate undergrowth. The Forest Service had prescribed the elimination of non-merchantable dominated trees, to interrupt vertical continuity of fuels. Non-merchantable trees were to be cut and lopped, to accelerate mineralization.

The operator would drive to the tree and position the head on the stem, then actuate the felling cut. The head would then push the tree towards its designed fall zone, and the feed rollers would pull the tree through the limbing knives. The operator would swing the boom to position the new log over the appropriate pile and then crosscut the stem. Limbing and crosscutting continued until the full merchantable length was processed. Finally, the top was dropped in front of the tracks, to reduce soil disturbance and limit track slippage. Long tops would be lopped. Our timestudy form split the work cycle according to this routine, and a precise description of the individual time elements is reported in Appendix A.

Table 4: Study outline

		Natural forest	Plantation
Study duration	days	3	2
Total observation time	hours	32.8	9.8
Total work time (excl. meals)	hours	29.2	8.6
Rest breaks	hours	2.1	0.5
Maintenance and repairs	hours	7.6	1.7
Mech. Availability	%	74.0	80.2
Total time of valid obs.	hours	15.5	5.9
Trees harvested (valid obs. only)	n.	1,065	415
Volume harvested (valid obs. only)	m3	381	67

4. Results

The main results of the study are shown in Table 5. A utilization rate of 65% was assumed (1). In the natural stand, the harvester averaged a net productivity of 70 trees/PMH, equal to 25.1 m3/PMH. In the plantation, productivity still reached 70 trees/PMH but volume output dropped to less than half, due to the much smaller tree size. These values are consistent with those in other CTL studies conducted in the western US and Canada (Drews et al., 1998; Hartsough et al., 1997; Hunt and Mitchell, 1995; Kellogg and Bettinger, 1994;) Schroder and Johnson, 1997; Spinelli and Hartsough, 1999).

The effect of rugged terrain and uneven stand characteristics is clearly visible: moving represents 25 to 30% of the total cycle time and brushing accounts for another 10%. Other tasks constitute a further 15% and include moving logs, placing slash under the tracks and looking for marked trees.

Basically, about half of the cycle time is spent preparing for productive work, rather than working. Felling and processing use very little time. Delimbing is very fast, unless the tree is big or the branching is bad. When the limbing resistance increases, the rollers tend to slip and tear the bark. In turn, loose bark interferes with the log length reading. The length encoder wheel "jumps" over hanging bark and eventually loses its measurement. The operator then has to repeat the whole procedure. At these elevations, August is the sap season and therefore the test was carried out at the most unfavorable time for the processor. Indeed, if the bark began to peel off, the operator preferred to run the tree through the head a number of times to obtain complete debarking. Then he could roll back to the butt, activate the saw to set the zero reading and produce logs without further interference from loose bark.

For the rest, the Valmet head could handle even malformed trees. Narrow forks were managed by slightly opening the knives, so that they could hit the forks higher up and break them. If this maneuver wouldn't do, the operator could always drop the tree and reposition the head with the saw towards the fork, in order to cut it. The two tops would then be handled individually.

The average cycle time is almost identical for trees grown in a plantation and trees grown in a natural stand. Element breakdown is different, however. In the plantation, thick undergrowth and low branching had the strongest effect on time consumption. Both reduced visibility, increasing the time required to locate marked trees and to move towards them.) Brushing time was twice as high in the plantation as in the natural stand, and positioning time was also longer - due to the low branches. On the other hand, felling, limbing and processing went somewhat faster, since the trees were much smaller and had lighter branching.

Table 5: Productivity of the Valmet 500T harvester

	Natural forest			Plantation		
Observations (n.)	1065			415		
Time Element	Mean	Std.Dev.	% of cycle	Mean	Std.Dev.	% of cycle
Move (cmin)	22.7	35.1	26.6	26.3	31.5	30.8
Brush (cmin)	4.3	10.3	5.1	11.3	21.8	13.3
Position (cmin)	8.0	5.3	9.4	8.9	5.0	10.4
Fell (cmin)	4.4	3.0	5.1	3.6	1.8	4.2
Handle (cmin)	13.7	15.9	16.0	10.2	12.8	11.9
Limb (cmin)	13.3	14.4	15.6	11.5	12.1	13.4
Crosscut (cmin)	5.6	5.1	6.6	4.1	3.7	4.8
Other (cmin)	13.3	24.2	15.6	9.6	25.2	11.2
Total cycle time (cmin)	85.3			85.4		
Logs/Cycle (n)	1.6			1.6		
Volume/tree (m^3)	0.357	0.363		0.161	0.122	
Trees/PMH	70.3			70.2		
Trees/SMH	45.7			45.6		
m^3/PMH	25.1			11.3		
m^3/SMH	16.3			7.3		

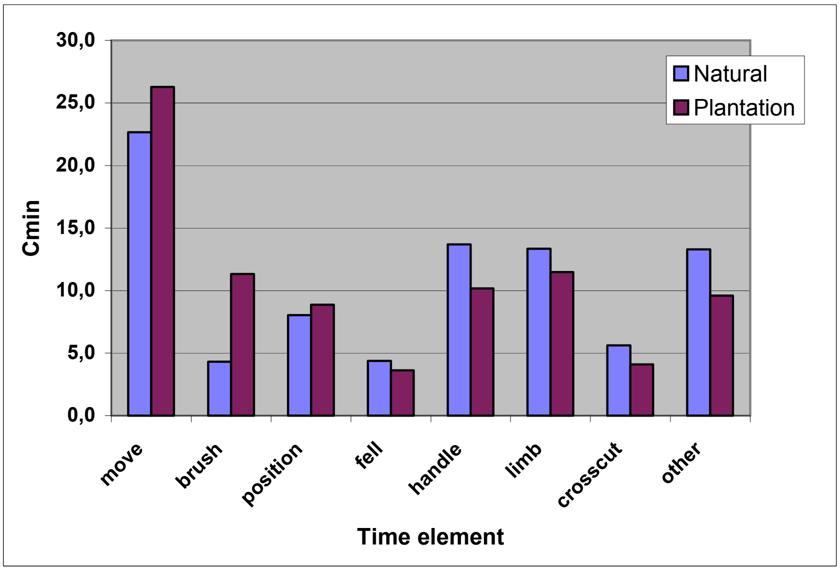

Figure 1: Harvesting cycle: time-element breakdown

Table 6: Saw chain durability and maintenance

Stand	**Natural forest**	**Plantation**
n° trees	1065	415
n° chains	8	5
n° slip-offs	19	15
trees/chain	133.1	83.0
trees/slip-off	56.1	27.7
time to reinstall/event (cmin)	332.9	211.1

One problem with chainsaw-type harvester heads is the intrinsic vulnerability of the cutting chain. Our study checked that too, and the results are shown in table 6. Newly sharpened chains felled and processed 80 to 130 trees on average before they had to be replaced because the teeth had become dull. Between replacements, the chain came off the bar about 3 times on average, and putting it back on the bar took about 2-3 minutes. Neither chain wear nor slip-off rate seem to be higher than in motor-manual processing. Much depends on visibility. In the plantation, thick undergrowth and low branching made it difficult for the operator to detect obstacles near the tree butt, which explains a higher frequency of both slip-offs and chain replacements.

Data were analyzed statistically, to reveal relationships that govern the harvesting process. On this basis, we developed a series of regression models that can help predict time consumption as a function of the most significant independent variables: slope, tree volume, branching etc. The prediction models obtained from our study are shown in Table 7. All the terms in the equations are highly significant ($p<.01$), but few can account for more than half the variability. This is logical for a highly variable process affected by a number of factors that could not be all included in our data collection. Microenvironment, operator concentration and tree position are among such factors.

Table 7: Productivity relationships

Time (cmin)	Regression	r^2	n. obs
Move =	22.65 + 4.92 (Plantation)	-	1399
Brush =	4.32 + 6.27 (Plantation)	-	1399
Position =	8.04 + 0.87 (Plantation)	-	1399
Fell =	2.82 + 1.41 (Br * Vol)	0.419	1399
Handle =	1.69 + 1.34 (Br) + {8.12 + 5.65 (Plantation)}*Br*Vol	0.472	1399
Limb =	-0.55 + 2.36 (Br) + {7.41 + 9.53 (Plantation)}*Br*Vol	0.541	1399
Crosscut =	1.23 + 4.94 (Vol) + 0.40 (Br) + {1.41 + 1.41 (Plantation)}*Br*Vol	0.553	1399
Other =	13.30 – 4.37 (Plantation)		1399
Where:	Vol=tree volume (ft^3) Br= Branching (class) Plantation = Plantation indicator = 1 if trees are pines from plantation, otherwise 0		

The time spent handling, delimbing and crosscutting a tree is closely related to the characteristics of the tree - namely to its volume and branching. These two factors seem to compound their effects, since we obtained the strongest correlations with functions of the "volume x branchiness" variable. That means that time consumption is high for large trees and for branchy trees, and much higher for those trees that are both large and branchy. No significant difference was found for the handling, delimbing and crosscutting times of different tree species: the other variables in the equations already accounted for specific characters (i.e. size, branchiness) that affect the duration of these time elements. ANOVA tests also showed that a number of time elements are longer for plantation trees than for naturally regenerated trees. The graphs in Figure 2 are based on these relationships and allow predicting net productivity as a function of tree size and branchiness.

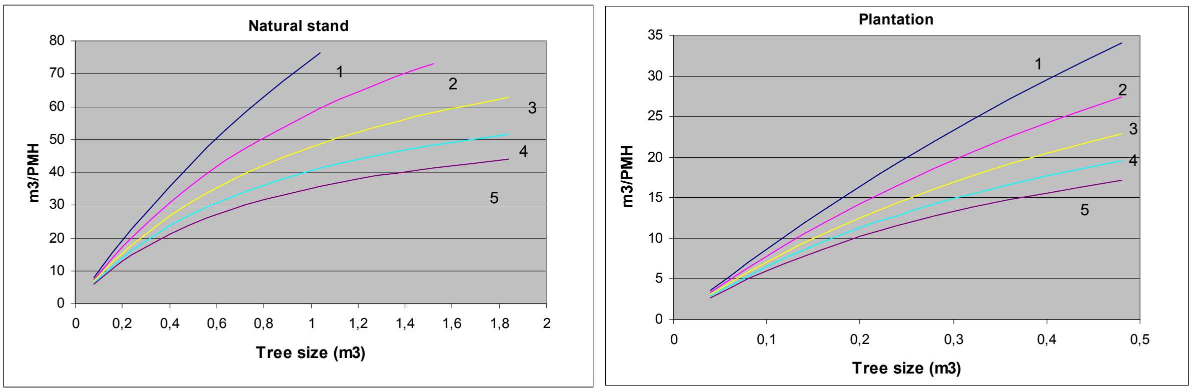

Figure 2: Productivity as a function of tree volume for each branching class

5. Conclusions

The Valmet 500T can negotiate rough terrain and is flexible enough to harvest different stand types. During the study, the machine handled steep slopes and thinned both a natural stand and a young plantation. The plantation was much more difficult to harvest, due to the thick undergrowth and to the persistent lower branches on the trees. Productivity was further limited by the very small tree size: harvester productivity depends on a number of factors, among which tree size and shape are most important. The study provided a set of equations that allow calculating productivity as a function of tree size and branchiness. The results are shown in graphic form for immediate use.

The working pace of the machine is very fast, which helps when processing small trees. Comparatively good productivity is achieved for individual tree volumes of 0.25 m3 or higher. Much below this threshold, productivity drops more substantially. As to the upper limit, the machine could harvest trees larger than 1.6 m3. Natural stands may contain some trees that exceed this limit: they should be felled and processed motormanually by an operator hired for the purpose.

The hydraulic chainsaw mounted on the European-style harvester heads is somewhat more vulnerable than the disc saws found on feller-bunchers or on some American harvesters. The study checked that too, indicating that the problem is not too serious. Much depends on visibility: accidental contact can be avoided if the operator can see the area around the tree butt. In this case, a sharp chain may cut twice as many trees before it becomes too dull.

CTL technology is very interesting, because it offers the benefits of limited environmental impact, simpler logistics and increased operator comfort. Modern self-leveling carriers and efficient harvesting heads can take CTL technology to rough terrain and selection cuts, once considered beyond its range of applications.

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Appendix A: Description of time elements

Time elements:	move=any moment tracks are rolling brush=removal of undergrowth and unmerchantable trees position= from when tracks stop (or brushing ends) to when the chainsaw begins cutting fell=from when the chainsaw begins advancing to when the tree starts to fall handle=any movement of the boom while the head holds a cut tree, provided the machine is not doing any other job (i.e. limbing etc.) limb=cut tree being propelled through the knives' embrace crosscut=any time one the saw is being operated to crosscut other=any other productive time, mostly clearing the path from obstacles, re-handling, piling slash, ejecting tops and trying to locate the next target tree